Appendix H3
Acoustic Study

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Project Title:	Subject:
CABRILLO PORT LNG TERMINAL	**ACOUSTIC STUDY**

CJ ENGINEERING CONSULTANTS
ACOUSTICS AND VIBRATION ENGINEERS

ACOUSTIC STUDY

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1 EXECUTIVE OVERVIEW

The study has estimated the underwater-radiated noise and the airborne radiated noise using preliminary design drawings and equipment lists for the FSRU. The estimation process used a source – transmission path – receiver model to estimate the underwater-radiated and airborne noise from the FSRU.

For the standard operating state of the FSRU, the octave band levels for the underwater-radiated noise varied from 145 dB re to 179 dB re 1 µPa @ 1 m. The total broadband level from 22 Hz to 11300 Hz was 182 dB. It is estimated that the FSRU would be in this state for 90% of the time. The level will fall to 122 dB at 1 km and will be equal to the background level on a windy day at a distance of less than 7 km.

When the FSRU is operating at maximum capacity of 1.5 Bscfd, which represents the maximum hourly gas demand, the octave band levels for the underwater-radiated noise varied 146 dB to 180 dB re 1 µPa @ 1 m. The total broadband level from 22 Hz to 11300 Hz was 182.5 dB. The level will fall to 122.5 dB at 1 km and be equal to the background on a windy day at a distance of 7 km.

The maximum radiated noise levels were calculated when the FSRU was using its thrusters. In this situation, the underwater-radiated noise is dominated by the noise from the thrusters and hence independent of the operating condition of the FSRU. This situation will occur on average for 11.5 hrs per week during the berthing of LNGC shuttles.

The noise predictions for the FSRU showed the levels were lower than those for a supertanker.

The sound pressure level at 1 meter from a point source with the equivalent total sound power of the FSRU is 127 dB(A). The general airborne levels on the deck will be much lower than this. The sound pressure level will fall to 67 dBA at 1 km, and will be less than 50 dBA at a distance of 5 km.

The estimation procedures provide the sound pressure levels at 1 meter from a point source with the equivalent total sound power. This allows calculation of the far-field levels and provides standardized levels for comparison. However, it is not possible to provide accurate estimates of the levels in the near-field. Because the FSRU is a large distributed source, the actual near-field pressure levels will be lower than those predicted by the simple lumped source estimates.

2 INTRODUCTION

BHPBilliton Petroleum is developing a floating LNG receiving terminal (FSRU – Floating Storage and Re-gasification Unit) to be permanently moored about 14 miles offshore Ventura County, California. The FSRU will receive regular shipments of LNG from LNG carriers, transfer it to the onboard storage tanks, then re-gasify it and transport the gas to shore through two new sub sea pipelines.

BHP Billiton has commissioned CJ Engineering Consultants, Acoustics and Vibration Engineers to undertake acoustic studies for the Cabrillo Port LNG Floating Storage and Regasification Unit (FSRU) located off the coast of California. The study includes estimation of underwater-radiated sound levels and airborne sound levels.

CJ Engineering Consultants worked closely with WorleyParsons who have been involved in design development for the FSRU. A brief summary of CJ Engineering's expertise and experience has been provided in Appendix A.

The study considers seven operating cases for the FSRU. The estimation processes is based on a source → transmission path → receiver noise model. The machinery noise sources are characterized by airborne sound power and vibration source levels. The load cases are outlined in section 3 and sections 4 and 5 provide a description of the methodology and the assumptions in the analysis. In sections 6 and 7 respectively the source and transmission path data is presented; while section 8 presents the radiated noise estimates for each operating case.

3 SCOPE

The study scope involved determination of the Cabrillo Port facility waterborne and airborne acoustic signatures. Seven operational scenarios were developed that cover the range of operating conditions for the FSRU. The following operating scenarios were considered:

Case 1: Base case, the FSRU on its own running at 800 MMscfd. This represents the operational state of the FSRU for 90% of the time. Equipment selection for this case was based on good engineering practice and not on a worst case of the maximum possible operating equipment.

Case 2: FSRU as above but running at 1.5 Bscfd. Additional operating equipment was included in this case as necessary to accommodate the additional load.

Case 3: Same as base case (case 1) but main contributing equipment suitably (but practically) suppressed.

Case 4: As base case (case 1) but with carrier alongside for the day loading, no tugs.

Case 5: As case 4 but with tugs and maneuvering either side of the loading sequence

Case 6: FSRU running at 1.5 Bscfd but with tugs and maneuvering.

Case 7: FSRU running at 1.5 Bscfd and the IGG operating

This revision of the report has incorporated the effect of the seawater cooling elimination project on the noise signature of the FSRU (Ref. 11).

The study has estimated the radiated noise levels using preliminary design drawings and equipment lists. Manufacturers' noise data for the equipment has been used where available, otherwise the noise source levels of the equipment has been estimated using generally accepted expressions from the literature. As the final structural design has not been completed, noise transmission from the machinery source through the ship structure and into the water was estimated using a series of transfer functions for the various path elements. Expressions used are derived from a mix of acoustical theory, empirical formulations based on practical experience and measured data.

The analysis has been performed in octave bands from 31.5 Hz centre frequency to 8000 Hz centre frequency. This gives a broadband frequency range of 22 to 11300 Hz. The study used a source-transmission path-receiver model to estimate the underwater-radiated noise and the airborne radiated noise from the FSRU.

Noise sources were represented in terms of vibration levels and radiated sound power levels. For each machinery item, the transmission paths to water or air were identified. These transmission paths were subdivided into path elements and the transfer function for each element was estimated. These were then combined to determine the overall transmission path transfer function. Finally, the receiver properties and the transmission to the receiver (either water or air) were estimated and combined with the source data and transmission path data to arrive at an estimate of the radiated noise.

4 METHODOLOGY

The following noise prediction methodology has been used to determine the airborne and waterborne acoustic signature for the FSRU. The procedures for estimating the underwater-radiated noise and the airborne radiated noise are essentially the same, only the final medium is different.

4.1 NOISE SOURCES

The technical approach to the radiated noise estimation procedure is based upon a source → transmission path → receiver noise model. The machinery noise sources are characterized by airborne sound power and vibration source levels. Machinery noise sources are a function of rated power, rotational speed, number of blades, number of pistons etc. Where manufacturer's data was available this has been used in the prediction model, otherwise generic prediction procedures for estimating airborne and structure-borne noise source levels were used. All machinery sources that were considered to contribute measurably to the total noise signature were included in the model. However, to reduce the complexity of the analysis where practical, smaller noise sources were combined to form a single point source and included in the calculation.

4.2 TRANSMISSION PATHS

For each machinery noise source the various transmission paths were determined, representing the ways that acoustic energy is transmitted from the source to the receiver.

The paths are made up of a number of elements, some structural and some acoustical. The transmission paths are represented quantitatively by a series of transfer functions. These express the input/output relations between excitation and response for the various transmission path elements. The transfer function is typically a frequency dependant function, which is expressed in decibels. A combination of measured data, acoustical theory, numerical modeling and practical experience was used to provide the transmission path estimates.

Schematics for the structure-borne and airborne paths for a machine are shown below.

Figure 4-1: Acoustic Transmission Paths

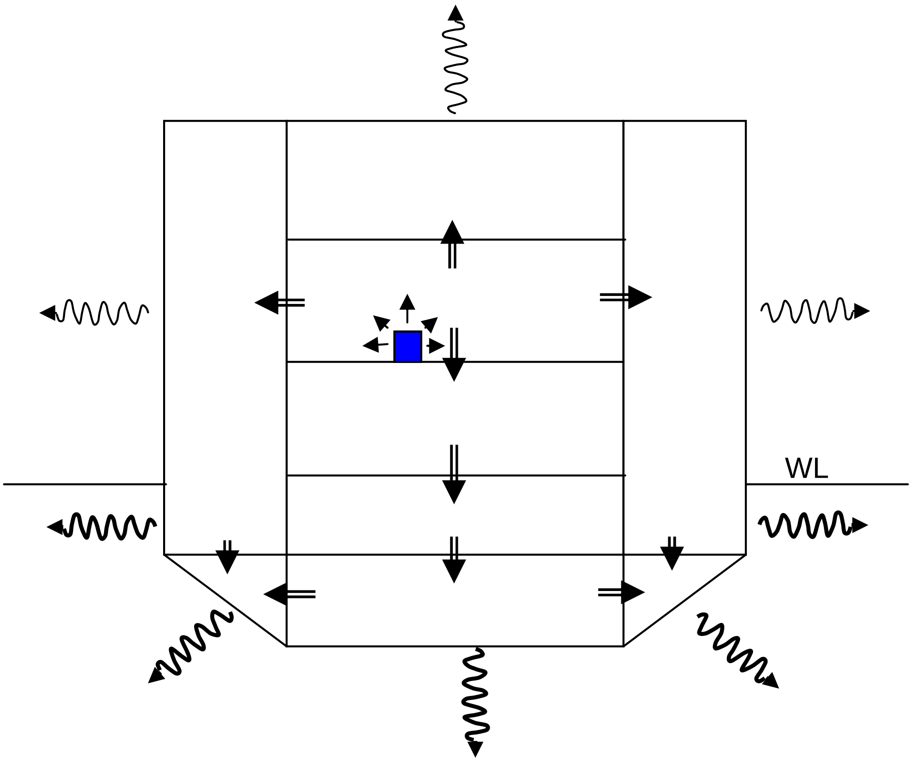
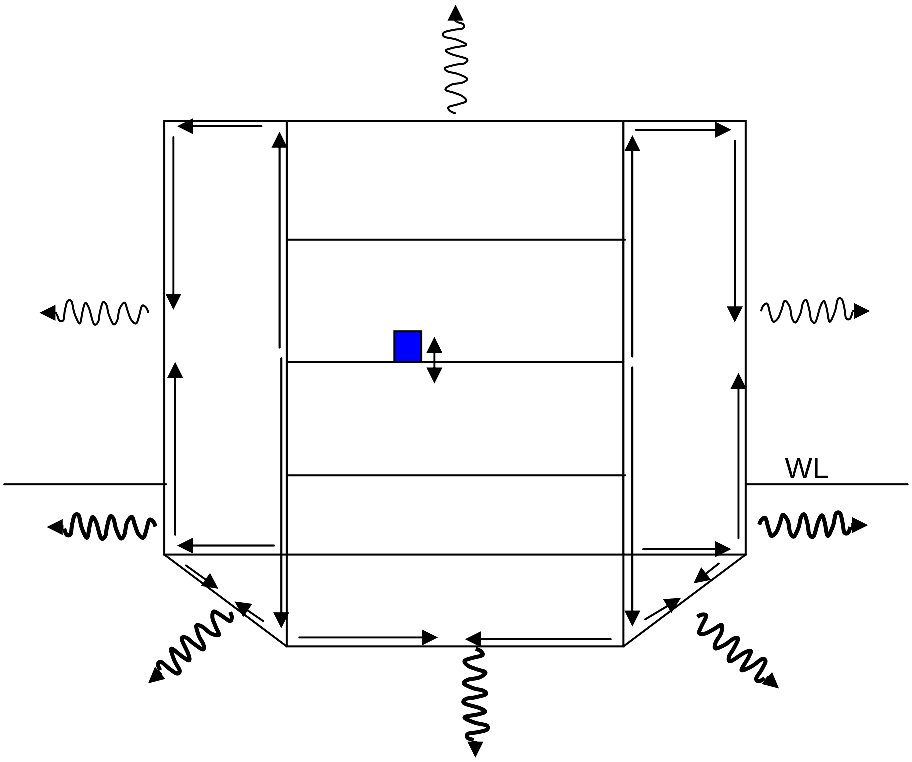


Figure 4-2: Structural Transmission Paths



4.3 ACOUSTIC TRANSMISSION

For underwater-radiated noise estimates, models of the hull radiation efficiency and through hull acoustic transmission were used to provide estimates of the near field acoustic radiation. A noise propagation model was then used to provide estimates of the noise at distant locations.

For the above water airborne radiated noise, models of the hull and deck radiation efficiency and the through hull acoustic transmissions to air were used to provide estimates of the near field radiated noise. These were combined with the radiated noise from deck-mounted machinery and then a propagation model was used to provide estimates of the airborne noise at distant locations.

In calculating the airborne noise transmission the sound pressure levels in each of the machinery spaces were estimated

The prediction included all noise sources that are reasonably considered to contribute to the total radiated noise. Similarly, the model needs to include all transmission paths for which energy is transmitted from the noise sources to the sea.

4.4 PROCEDURE

The work steps for the study are summarized below.

Task	Description
	Define, list and locate all machinery items.
	Define machinery line-ups for each operating state/condition (see options below table)
	Determine and list machinery characteristics - as power, speed etc for each machine
	Investigate manufacturer’s noise source data, or calculate noise source strength for each machine
	Apply mount transmission loss and foundation transmission loss to obtain deck velocity levels.
	Identify the location of each machine or group of like machines within the structure, identify the structural transmission paths for each machine
	Define transmission path transfer functions and calculate the velocities at the centre of each wetted hull panel
	Calculate radiated noise level in water or the air from predicted hull vibrations
	Identify the airborne transmission paths for airborne radiated sound power from each machine
	Define transmission path transfer functions and calculate the radiated noise via airborne transmission
	Calculate contribution to waterborne noise and airborne noise from airborne noise with vessel equipment rooms

Task	Description
	Combine radiated noise levels for defined machinery line-ups
	Predict far-field levels at defined distances

In order to simplify the analysis for a number of small machinery in the one location the vibration power levels were combined to give an equivalent source strength and the transmission path transfer functions were used with this source.

The key input data used for the study is the FSRU equipment list in Appendix B.

5 ASSUMPTIONS

The following assumptions have been made in the calculations of waterborne and airborne noise:

1. Where manufacturer's data is available for machinery noise and vibration source strength, this has been used. Otherwise, generalised expressions for a particular machine type have been used to calculate the vibration and noise source levels.

2. Only primary structure-borne and airborne noise transmissions have been considered. Secondary paths, such as the airborne noise excitation of decking and the structure-borne transmission of this vibration have been ignored in order to simplify the problem.

3. Hull vibrations due to machinery are considered important within the hull area bounded by the nearest bulkheads and the adjacent hull area bounded by the next bulkhead. They are not considered to extend into the hull beyond this.

4. The radiated noise from individual machines is calculated separately and then the noise from all machines is summed incoherently. This implies that all machines are independent and incoherent sources.

5. Structure-borne transmission losses are estimated using empirical expressions. For this purpose, the hull structure has been simplified as represented by Figure 4-1 and Figure 4-2

6. For transmission of sound into the water, the vessel water line is assumed to be 13,200 mm above the keel line

7. The averaged vibration levels within a hull section are represented by the value at the centre.

8. The airborne sound field within an enclosed compartment is diffuse.

9. Enclosed machinery compartments are assumed to be reverberant.

10. The interior of the machinery compartments are considered hard for the purposes of estimating the room acoustic properties.

11. Machinery is assumed to be mounted on a foundation and not fixed directly to the deck structure.

12. The above deck structure at the forward end can be represented as being on a pseudo deck of equal thickness to the top deck, separated by stanchions.

13. On machinery floors, vibration levels on that floor are assumed to come only from machines on the same floor and not from other floors.

14. Between frames 10 and 27, the 16 frames with cutout plates shall be assumed to be equivalent to a single full plate at about frame 18 for the purpose of estimating transmission levels.

15. Vibration source level for motors have been set 3 dB higher for all frequencies than base levels quoted in Nelson for a motor subjected to vibration performance requirements.

16. In calculating floor vibration levels at the walls, this level will be based on the shortest distance from the equipment to the wall.

17. For the purpose of estimating transmission of airborne noise and vibrations to the hull, the ballast tanks are assumed to be empty, which corresponds to the LNG tanks being full.

18. As the maximum standard noise in cabins is 60 dBA, negligible emission to the outside from living quarters has been assumed.

19. Noise and vibration from the LNG transfer pumps located within the LNG spheres has been assumed to be insignificant outside of the spheres.

20. For vibration purposes, any equipment with a power rating less than 5 kW has been ignored.

21. Groups of equipment with powers ratings between 5 and 20 kW on a particular floor location have been represented by one item of equipment of a size that emits the same vibration level as the separate items of equipment combined.

22. The cranes, which operate intermittently, have a relatively low motor power rating (20 kW) and are mounted on legs above deck. Therefore, their contributions to hull vibration levels have been considered negligible.

6 SOURCE LEVEL ESTIMATES

Each of the machinery sources were described in terms of acoustic source strength and vibration source strength. The source strength chosen should be independent of the environment and a function of the machine only. Acoustic sound power and free velocity levels were chosen as the acoustic and vibration source strengths respectively.

The sound power level radiated by an object is independent of the surrounding environment where the measurements are made, whereas the sound pressure level measurements are a function of the sound power and the surrounding acoustic environment.

Sound power level $L_w = 10 \log_{10} W/10^{-12}$ dB re 10^{-12} watts

Free vibration levels were selected to describe the vibration strength of sources. The free vibration level refers to the vibration that exists in the absence of any connections to supporting structure. Thus, they are a function of the machinery source only. In practice, “free” vibration levels are the vibration levels that are measured above very low frequency mounts.

Free velocity levels $L_V = 20 \log_{10} V/10^{-6}$ dB re 10^{-6} cm/sec

Where manufacturer’s data was available for the machinery source levels it was used in the calculation process. The reliability of the supplied data was checked using empirical estimation procedures to ensure it was within the expected range.

Where manufactures data was not available, estimation procedures were used to derive source levels. The procedures for estimating the source levels were

1. Determine a base level, which is generally a function of the machine power, weight and/or speed

2. Adjust the baseline level for operational parameters and deviation from design operational point

3. Convert baseline level to octave band levels using octave band adjustments

The following material in this section describes the general approach to estimating the source levels. Detailed lists of the estimated levels for each item of equipment are presented in Appendix C.

6.1 GENERATOR ENGINES

In ships and maritime applications, marine diesel engines are commonly used for propulsion and as electrical service prime movers. In the case of the FSRU, dual fuel marine engines are proposed that have similar vibration and acoustic emission levels to a marine diesel engine for which empirical estimates are available. During normal operation of the FSRU, the engines will be fuelled by LNG boil-off gas; only during emergencies or FSRU start-up will diesel be the primary fuel source.

One of the manufacturers of the dual fuel engines, Wartsila, has provided typical vibration and airborne noise data for the engine. This was compared against vibration and airborne noise data calculated using standard form expressions as a check. At this stage of the design, the final vendor of the dual fuel engines has not been selected but Wartsila has been used as the basis for this study.

Manufacturer's data supplied for typical levels of the engine are:

	Octave band centre frequency (Hz)								
	31.5	63	125	250	500	1000	2000	4000	8000
Lv (dB)	119	108	107	105	104	94	84	N/A	N/A
Lw (dB)	120	116	115	115	119	116	114	112	106

Manufacturers' Data for Vibration and Acoustic Source Levels of the Generator Engine

Expressions for the vibration velocity levels and radiated sound power from the literature were used to estimate the expected levels from the engine, as a check on the levels provided by the manufacturer. The baseline vibration levels are a function of the engine power, mass and speed, while the radiated noise levels are a function of power.

The estimated levels are:

	Octave band centre frequency (Hz)								
	31.5	63	125	250	500	1000	2000	4000	8000
Lv (dB)	107	106	106	105	104	104	100	92	81
Lw (dB)	115	115	121	122	120	118	114	107	98

Estimated velocity and radiated sound power of generator engine

The manufacturer's data for both vibration and radiated sound power was considered satisfactory and was used in the estimation procedure.

6.2 GENERATOR

The estimation procedures for vibration levels and radiated sound power for an electrical generator are given in the literature and are a function of the power and speed of the generator. Using these expressions the estimated velocity and noise levels of the generators are:

	Octave band centre frequency (Hz)								
	31.5	63	125	250	500	1000	2000	4000	8000
Lv (dB)	114.1	119.1	116.1	110.1	106.1	101.1	96.1	90.1	84.1
Lw (dB)	100	103	105	105	104	102	100	97	92

Vibration and Acoustic Source Levels for the Generator

6.3 ELECTRIC MOTORS

Equations predicting the vibration levels of AC electric motors were not found in the literature surveyed. Estimates of vibration levels, which are taken as independent of motor size, speed and rated load, are shown below. These values are 3 dB higher than the levels quoted by

Nelson for motors purchased to a performance requirement and are considered more representative of commercial "off the shelf" units.

Octave band centre frequency (Hz)									
	31.5	63	125	250	500	1000	2000	4000	8000
Lv (dB)	99	93	87	81	75	69	63	57	51

Vibration Source Levels for AC Electric Motors dB re 10^{-8} m/s

Bies and Hansen and Nelson provide expressions for the estimation of the radiated sound power from electric motors. The expressions are a function of the motor power and running speed. These were used to estimate the radiated noise from each of the electric motors.

6.4 PUMPS

Expressions for the baseline vibration levels from centrifugal and gear pumps were taken from the literature. The baseline levels are a function of the pump power. The expression was used to calculate the baseline level for each of the pumps onboard the FSRU.

The octave band adjustments depend on the type of pump and are:

Octave band centre frequency (Hz)									
	31.5	63	125	250	500	1000	2000	4000	8000
Centrifugal Pump (dB)	10	12	19	11	9	4	-6	-8	-15
Gear Pump (dB)	20	25	32	24	23	18	12	7	0

Octave Band Adjustments for Pump Vibration Levels

Manufactures data was available for the radiated noise of the selected pumps and this was used as the source levels for this equipment.

6.5 RECIPROCATING REFRIGERATION PLANT (AIR DRYERS)

Expressions for the vibration level on reciprocating refrigeration plant were taken from the literature and used to estimate the levels for the various machinery items.

Manufacturer's data for the airborne noise from the reciprocating refrigeration plant was available and was used in the estimations.

6.6 CENTRIFUGAL COMPRESSORS AND BLOWER UNITS

The vibration source levels for direct-motor driven blower units is given in the following table

	Octave band centre frequency (Hz)								
	31.5	63	125	250	500	1000	2000	4000	8000
Lv (dB)	94	108	112	101	95	94	93	87	86

Vibration Source Levels for Direct-Motor Driven Blower Units

These levels represent the source levels for plant of between 40 and 150 kW operating at 3600 rpm and are considered representative of most shipboard plant units.

Airborne source levels for the blower units were available from the manufactures and this data was used in the estimations.

6.7 SCREW PUMPS

Vibration levels for screw pumps are typically of the same order as the electric drive motor. Thus for the purposes of this estimation procedure 3 dB was added to the drive motor vibration levels to attain the combined level for the pump and motor.

Airborne source levels for the screw pumps were provided by the manufacture and this data was used in the estimation procedure.

6.8 LNG CARRIER

Estimates of the underwater-radiated noise from an LNG carrier during gas transfer were derived by scaling the radiated noise of the baseline case for the FSRU. During the transfer process, the LNG carrier will be moored to the FSRU and the LNG carrier will only be providing power for process equipment and hotel load; the carrier will not be using its propulsion system during this time. The LNG carrier will have a steam turbine power system, which is quieter than the equivalent diesel generator system.

The power requirement for the LNG carrier during the transfer process was estimated to be 1.5 MW, which is 10% of the power capacity of the FSRU during the base load case. Assuming a similar percentage of radiated noise, the underwater noise levels from the LNG carrier will be 10 dB lower than the base load case levels of the FSRU.

6.9 TUGS

Levels for a tug towing a loaded barge at 18 kts are reported in the literature. Some data for icebreakers operating with the same bollard pull as the tugs in case 5 was also available to the in Thiele. The underwater-radiated noise levels from the tugs was estimated as

	Octave band centre frequency (Hz)									
	31.5	63	125	250	500	1000	2000	4000	8000	Broad band
Source level (dB)	160	170	170	168	162	156	150	144	138	175

Underwater-Radiated Noise Levels for the Tugs

To estimate the airborne levels from the tugs it was assumed that the source of airborne noise was the exhaust from the main diesel propulsion engine. This was taken to be half the radiate sound power of the exhaust noise from a diesel generator on the FSRU.

6.10 THRUSTERS

Estimates of the underwater-radiated noise from thrusters were derived by scaling data from the literature. These are given in the table below

	Octave band centre frequency (Hz)									
	31.5	63	125	250	500	1000	2000	4000	8000	Broad band
Source level (dB)	185	187	188	180	173	171	167	160	150	192

Underwater-Radiated Noise Levels for the Thrusters

7 TRANSMISSION PATH ESTIMATES

For underwater-radiated noise, the basic transmission paths are air-to-water, air-to-structure-to-water, and structure-to-water. Structural paths are those that transmit the machinery vibration to the water via the ship structure. The machinery vibration levels are transmitted into the machinery foundation, through the ship structure to the wetted hull, where it is radiated into the water.

Air-to-water transmission paths are those where the airborne radiated noise from machinery is transmitted through the ship compartments, and then into the water.

Structural vibrations in the ship structure can be radiated into the internal compartments and then transmitted as airborne noise. These are structure-to-air-to-water paths. Similarly, airborne noise can also excite the ship structure, where it is transmitted through the structure and then radiated into the water. These are air-to-structure-to-water transmission paths. For the purposes of this study, only air-to-water and structure-to-water transmission paths are considered.

7.1 STRUCTURE-BORNE TRANSMISSION PATHS

The structural transmission paths can be divided into three basic sections: transmission from the machinery to the foundation; transmission from the foundation to the ship deck structure; and transmission through the ship structure. The transfer functions for structural path components are most usefully described in terms of velocity transfer functions, since the machinery source levels are defined in terms of velocity and the noise radiated from the ship hull plates is directly related to the plate velocity.

7.1.1 Vibration Transmission from Machinery to Foundation

The machinery vibration source levels are described in terms of free vibration levels. Thus, it is appropriate to describe the vibration transfer function of the mounting system in terms of modified transmission loss. The modified transmission loss is defined as the difference (in decibels) between the free vibration levels of the machinery mounting points and the velocity below the mounting system with the machine mounted.

$TL = 20 \log (V_0/V_2)$, where V_2 is the velocity level below the mounting system on the foundation.

For machinery mountings, the sources of vibration are divided into three weight classes. Class 1 are sources weighing less than 450 kg (992 lbs); class II weighing between 450 and 4500 kg (9920 lbs); and class III weighing more than 4500 kg. Most of the machinery in this study fell into classes II and III.

Machinery weighing more than 2000 kg (4400 lbs) was assumed to be on rigid foundation structures constructed from elements similar to hull framing. This type of foundation is generally referred to in the literature as Type B foundations. Equipment weighing less than 2000 kg was assumed to be on lighter foundations classed as type A foundations.

Machinery may be attached to the foundation either directly as a hard mount arrangement or through isolation mounts. Isolation mounts may be either the DIM (Distributed isolation material) type or low frequency mounts. Value for the transmission loss for vibration transmission between machinery and foundation for each mounting arrangement are given below.

	Octave band centre frequency (Hz)								
	31.5	63	125	250	500	1000	2000	4000	8000
Hard Mount									
Class I	13	10	8	5	3	2	1	0	0
Class II	9	7	5	3	1	0	0	0	0
Class III	5	3	2	1	0	0	0	0	0
DIM									
Class I	13	11	9	8	10	15	15	15	15
Class II	9	7	7	6	8	8	9	10	10
Class III	5	4	3	3	3	3	4	5	6
LF Mount									
Class I	20	25	30	30	30	30	30	30	30
Class II	12	16	20	23	25	25	5	25	25
Class III	8	9	10	12	15	18	20	20	20

Transmission Loss for Different Machinery Mounting Arrangements for Type B Foundations (dB)

The transmission losses for the low frequency isolation mounts are considered conservative and are the minimum that could be achieved. Higher values would be possible by tailoring the mount design for the individual equipment. Still higher values are possible with the use of two-stage mounting systems.

7.1.2 Transmission through Ship Structure

Structure-borne noise is transmitted through ship structures as either bending or longitudinal waves. Bending waves are more efficient radiators of noise into air and water. However, wave transformations occur at structural discontinuities, such as bulkheads and deck junctions, throughout the ship structure.

The transfer functions throughout the ship structure are described in terms of transmission loss, which is the difference between the vibration level at the source and the receiver. The transmission loss for the ship structure has been divided into three broad categories; foundation to deck structure; through deck and hull plating; and at structural intersections.

The values of the foundation to deck transmission loss are a function of the foundation type and frequency. Values for these were taken from the literature and have been included in Appendix C.

The vibrational energy transmitted from the foundation into the deck structure immediately around the machine causes the plating to vibrate with a forced response. In the area immediately around the machinery foundation there is considered to be no decay in the vibration levels. Outside this area, the transmitted vibration will decrease as a function of damping in the ship structure. Losses will also occur at structural boundaries such as deck and bulkhead intersections.

Value for the dissipative losses in the ship structure and losses at the structural intersections were taken from the literature for use in the transmission path estimates. The transmission paths and nodes for the fore and aft ship sections have been shown in Appendix D.

7.2 AIRBORNE TRANSMISSION

Airborne noise energy is lost as it is transmitted through the ship structure. In this study, the main transmission path losses are considered to be due to the transmission from compartment to compartment in the ship.

The sound pressure within the machinery compartment is a function of the radiated sound power and the compartment acoustical properties. The machinery spaces were considered to be reverberant and the sound fields inside them were considered to be diffuse. Thus, the sound pressure level in the machinery space due to radiated sound power from the machinery is given by the expression

$Lp = Lw + 10\log(4/R)$, where

Lp is sound pressure level in dB re 20 μPa

Lw is radiated sound power in dB re 10^{-12} W

R is room constant, a function of room surface area and absorption coefficient of room surfaces.

The machinery space was all considered to be hard and the absorption coefficients used were:

	Octave band centre frequency (Hz)								
	31.5	63	125	250	500	1000	2000	4000	8000
Sabine Absorption Coefficient	0.1	0.1	0.09	0.05	0.02	0.01	0.01	0.01	0.01

Sabine Absorption Coefficients for Machinery Spaces

As noise is transmitted from one compartment to another, energy is lost. The amount of energy lost depends upon the partition material. The losses in airborne noise energy are expressed in terms of transmission loss, which is defined as the ration of the incident sound intensity to the transmitted sound intensity.

The sound pressure level in the receiving room is a function of the transmitted energy and the room acoustical properties. Thus the sound pressure in the receiving room is:

$L_2 = L_1 + 10\log(A) - 10\log(R) - TL$, where

L_2 is sound pressure level in the receiving room in dB re 20 μPa

L_1 is sound pressure level in source room in dB re 20 µPa

A is partition area

R is room constant for receiving room

TL is transmission loss for the partition.

For noise transmission through the ship plating into the water the sound pressure in the water is given by

$L_{2W} = L_1 + 10\log(A) - TL + 51$, where

L_{2W} is sound pressure in water in dB re 1 µPa @1m

L_1 is sound pressure level in source room in dB re 20 µPa

A is partition area.

Standard values for the transmission loss of the partition materials were taken from the literature.

7.3 ACOUSTIC RADIATION

The vibrating deck and hull plating of the ship will radiate noise into the surrounding air and water. The level of noise radiated depends on the amplitude of the plate vibrations, the frequency and the plate dimensions.

For radiation into air the radiated sound power is given by

$L_w = L_v + 10\log(A) + 10\log(\sigma) + 10\log n - 56$, where

L_w is radiated sound power in dB re 10^{-12} W

L_v is spatial averaged velocity of plate in dB re 10^{-8} m/s

A is area of a panel in cm^2

n is number of panels

σ is radiation efficiency of the panel.

The radiation efficiency is a function of frequency and panel dimensions. Values of the radiation efficiency for plates radiating into air either may be calculated using expressions in the literature or determined from nomograms given in the literature. Values used in the analysis are given below.

Octave band centre frequency (Hz)								
31.5	63	125	250	500	1000	2000	4000	8000
-16	-14.5	-13	-10.5	-4	2	0	0	0

Plate radiation efficiency, 10 log(σ), for 20mm thick plate in air for 3.7m frame spacing

The radiated noise levels into water are given by the expression

$L_{pw} = L_v + 10\log(A) + 10\log(\sigma) + 10 \log n + 35$, where

L_{pw} is radiated sound pressure level in water in dB re 1 μPa @ 1 m

L_v is spatial averaged velocity of plate in dB re 10^{-8} m/s

A is area of a panel in cm^2

n is number of panels

σ is radiation efficiency of the panel.

The values of the radiation efficiency for the hull panels were determined by numerical modeling using ACTRAN. Values used in the analysis are given below.

Octave band centre frequency (Hz)								
31.5	63	125	250	500	1000	2000	4000	8000
-40	-27	-27	-30	-23	-20	-17	-12	-8

Plate radiation efficiency, 10 log(σ), for water for 20 mm plate, 3.7m frame spacing

8 RADIATED NOISE

Results for the seven case studies are presented in tabular form below for both underwater-radiated noise and airborne radiated noise. These are also compared to estimated background levels and distances at which the noise from the FSRU becomes equal to the background level are presented.

There are machinery spaces in the bow and aft sections of the FSRU. Levels for the noise from each of these are presented separately and then the combined totals are given. Radiated noise levels for individual machinery groups are presented in Appendix F

The radiated sound pressure levels in the tables below refer to the sound pressure levels at 1 meter from a point source with the equivalent total sound power. This allows calculation of the far-field levels and provides standardized levels for comparison.

Background levels for the area have been estimated for calm, wind speed of 2 to 4 kts, and windy, wind speed of approximately 30 kts, conditions. [Urick, Wenz]

Octave band centre frequency (Hz)										
	31.5	63	125	250	500	1000	2000	4000	8000	Broad band
Calm	90.4	91.4	86.6	80.5	82.6	81.5	79.5	77.5	75.5	95.4
Windy	93.4	90.4	92.4	96.4	100.4	98.4	96.4	94.4	91.4	105.5

Background Underwater Noise Levels dB re 1 μPa

8.1 WATERBORNE NOISE

8.1.1 Case 1: Base Case

FSRU is exporting 800 MMscfd of gas only. This represents the operational state of the FSRU for approximately 90% of the time. Equipment operating states for this case were based on average load on the equipment and not on a worst case of the maximum possible operating states.

Radiated noise from fore and aft sections for each octave band are given in the table below. The total level for the broadband noise between 22 Hz and 11300 Hz s also included.

The total radiated noise levels will reduce to less than 122 dB at a distance of 1 km and will be equal to the background level on a windy day at a distance of less than 6.5 km.

	Octave band centre frequency (Hz)									
	31.5	63	125	250	500	1000	2000	4000	8000	Broad band
Fore	151.5	172.4	174.8	163.0	165.3	157.7	151.8	148.1	142.0	177.3
Aft	156.6	177.9	173.9	162.7	161.9	157.7	154.1	147.7	142.2	179.6
Total	157.8	179.0	177.4	165.9	166.9	160.7	156.1	150.9	145.1	181.6

Underwater Radiated Sound Pressure Level dB re 1 µPa @ 1 m

8.1.2 Case 2: Peak Gas Send-out

FSRU is exporting gas at 1.5 Bscfd. This represents the 1 hour peak load on the FSRU and is not a continuous operating scenario. Case 2 operation allows surges in gas demand of the Southern California gas network to be accommodated.

Additional operating equipment was included in this case as necessary to accommodate the additional load.

The radiated noise from fore and aft sections for each octave band is given in the table below. The total level for the broadband noise between 22 Hz and 11300 Hz s also included.

	Octave band centre frequency (Hz)									
	31.5	63	125	250	500	1000	2000	4000	8000	Broad band
Fore	151.6	172.9	175.1	163.1	165.3	157.8	152.0	148.1	142.4	177.6
Aft	157.8	179.0	175.0	164.0	163.4	159.3	155.9	149.3	143.8	180.7
Total	158.8	180.0	178.0	166.6	167.5	161.6	157.4	151.8	146.1	182.5

Underwater Radiated Sound Pressure Level dB re 1 µPa @ 1 m

The radiated noise increases by less than 1 dB overall compared to the base load case. The level will reduce to less than 123 dB at a distance of 1 km and be equal to the background level on a windy day at a distance of 7 km.

8.1.3 Case 3: Base Case with isolation mounts

In this load case, the same equipment as for the base case is operating but selected equipment is now mounted on vibration isolators. The level of vibration isolation included is considered the lowest that could be easily achieved. In practice, it is expected that a much higher level of isolation could be attained.

The radiated noise from fore and aft sections for each octave band is given in the table below. The total level for the broadband noise between 22 Hz and 11300 Hz is also included.

	Octave band centre frequency (Hz)									
	31.5	63	125	250	500	1000	2000	4000	8000	Broad band
Fore	150.8	170.9	170.7	160.0	163.3	155.1	150.7	145.6	136.7	174.4
Aft	154.4	174.4	169.9	157.0	152.1	146.8	139.5	133.5	131.6	175.8
Total	156.0	176.0	173.3	161.7	163.6	155.7	151.0	145.8	137.9	178.2

Underwater Radiated Sound Pressure Level dB re 1 μPa @ 1 m

For the internal combustion engine generator set the radiated noise decreases by 2.5 dB compared with the base load case. The level will reduce to less than 119 dB at a distance of 1 km and will be equal to the background level on a windy day at a distance of less than 5 km.

8.1.4 Case 4: LNG Transfer

In this load case, the FSRU is exporting gas at 800 MMscfd with an LNG carrier tied-up alongside. This mode of operation accounts for approximately 10% of the FRSU operating conditions.

The radiated noise from fore and aft sections for each octave band is given in the table below. The total level for the broadband noise between 22 Hz and 11300 Hz is also included

	Octave band centre frequency (Hz)									
	31.5	63	125	250	500	1000	2000	4000	8000	Broad band
Fore	151.9	172.8	175.2	163.4	165.7	158.1	152.3	148.5	142.4	177.7
Aft	157.0	178.4	174.3	163.1	162.3	158.1	154.5	148.1	142.6	180.0
Total	158.2	179.4	177.8	166.3	167.3	161.1	156.6	151.3	145.5	182.0

Underwater Radiated Sound Pressure Level dB re 1 μPa @ 1 m

There is a very marginal increase in the radiated noise compared with the base load case, and the levels for both generator types are almost the same. The level will reduce to 122 dB at a distance of 1 km and be equal to the background level on a windy day at a distance of less than 7 km.

8.1.5 Case 5: FSRU with LNG carrier and Tugs

The main noise source during the docking of the LNG carrier using tugs is the thruster on the FSRU. The total level for the combination of FSRU using thrusters, the LNG carrier and two tugs is given in the table.

Octave band centre frequency (Hz)										
	31.5	63	125	250	500	1000	2000	4000	8000	Broad band
Total	185	187.8	188.6	180.7	174.6	171.6	167.5	160.8	151.6	192.6

Underwater Radiated Sound Pressure Level dB re 1 µPa @ 1 m

These levels only occur whilst the thrusters are operating, on average 11.5 hours per week. When the thrusters are not operating, this case reverts to case 4.

The levels would fall to 132.6 dB at a distance of 1 km and be equal to the background level at 22.6 km.

8.1.6 Case 6: Peak gas send-out plus LNG carrier and Tugs

In this case, the FSRU is running at maximum capacity of 1.5 Bscfd during the docking of the LNG carrier using tugs. As noted in Case 2, the peak gas send-out condition will only occur for 1 hour intervals but may coincide with a LNG carrier docking operation as the two events are not linked.

The main noise source during this operating is the thrusters on the FSRU. The total level for this operation is given in the table.

Octave band centre frequency (Hz)										
	31.5	63	125	250	500	1000	2000	4000	8000	Broad band
Total	185	187.8	188.6	180.7	174.6	171.6	167.5	160.8	151.6	192.6

Underwater Radiated Sound Pressure Level dB re 1 µPa @ 1 m

These levels only occur whilst the thrusters are operating, on average 11.5 hours per week. When the thrusters are not operating, the levels are similar to case 4. The levels would fall to 132.6 dB at a distance of 1 km and be equal to the background level at 22.6 km.

8.1.7 Case 7: Peak gas send-out plus the IGG system operating

In this case, the FSRU is assumed to be running at its hourly maximum capacity of 1.5 Bscfd and inert gas generator (IGG) is operating simultaneously.

This operation is highly unlikely as the operation of the IGG infers the one LNG storage tank is out of service. The FSRU is unlikely to achieve its maximum capacity under this condition.

The radiated noise from fore and aft sections for each octave band is given in the table below. The total level for the broadband noise between 22 Hz and 11300 Hz is also included.

Octave band centre frequency (Hz)										
	31.5	63	125	250	500	1000	2000	4000	8000	Broad band
Fore	151.6	172.9	175.1	163.1	165.3	157.8	152.0	148.1	142.4	177.6
Aft	159.4	182.1	178.2	167.2	165.1	160.8	156.5	149.7	145.0	183.8
Total	160.0	182.6	179.9	168.6	168.2	162.6	157.8	152.0	146.9	184.7

Underwater Radiated Sound Pressure Level dB re 1 µPa @ 1 m

The operation of the IGG increases the radiated noise by 2 dB overall. The level will reduce to less than 125 dB at a distance of 1 km and be equal to the background level on a windy day at a distance of less than 9.5 km.

8.2 AIRBORNE NOISE

The radiated sound pressure levels in dBA re 20 µPa @ 1 m for the five case studies are summarized in the table below.

	Fore	Aft	Equivalent Total
Case 1 Base Case	127	118	127
Case 2	127	118	127
Case 3	118	114	119
Case 4	127	118	127
Case 5	127	120	128

Airborne Radiated Noise Levels in dBA re 20 µPa @ 1 m

Cases 6 and 7 were not assessed in detail as part of this revision. For case 6, the airborne noise levels would not be expected to increase significantly above the levels for case 5. Case 7 will not be different to Case 2 as the IGG is in the engine room and hence will not contribute to airborne noise.

The sound pressure levels in the table above refer to the sound pressure at 1 meter from a point source with the equivalent total sound power of the FSRU. The general airborne levels on the deck will be much lower than this. The sound pressure level will fall to 67 dBA at 1 km and will be less than 50 dBA at a distance of 5 km.

9 DISCUSSION

9.1 UNDERWATER RADIATED NOISE

The total underwater-radiated noise levels predicted for the seven cases studied vary from 182 dB for the FSRU by itself (90% operating time) to 183 dB for most operating modes.

Peak levels of 192 dB occur on average 11.5 hours per week while LNG carriers are maneuvered alongside the FSRU using two tugs.

The predicted noise levels from the FSRU are commensurate with similar floating platforms and are less than a large container ship, tankers or supertankers. Generally, the noise from the FSRU will be equal to the background levels at a distance of less then 7 km. The levels will fall to 120 dB at a distance of 1 km and will be equal to the background level, for a windy day, at a distance of less than 6 km.

The radiated sound pressure levels presented in the report refer to the sound pressure levels at 1 meter from a point source with the equivalent total sound power. This allows calculation of the far-field levels, and provides standardized levels for comparison.

The underwater radiated noise is distributed between the fore and aft sections of the FSRU, and is generally the result of structure-borne noise from the machinery installed in the below deck machinery compartments.

The radiated noise from the fore section is principally due to the fire-pump (a fire pump is only expected to be run during routine testing), which is located in underdeck level 5, while the noise level from the aft section is mainly due to the pumps on level 5 and the diesel-generators on level 3.

The results of case 3 show that the underwater-radiated noise levels may be reduced by at least 3 dB by resiliently mounting selected machinery items. The study included a minimum level of attenuation that could be easily achieved.

9.2 NEAR-FIELD VERSUS FAR-FIELD NOISE LEVELS

The radiated sound pressure levels presented in the report refer to the sound pressure levels at 1 meter from a point source with the equivalent total sound power. This allows calculation of the far-field levels and provides standardized levels for comparison. The actual near-field pressure levels will be less than these standardized values. The principle reason for this is that the hull is not a point source and therefore equipment separation will need to be considered for near-field noise profiles.

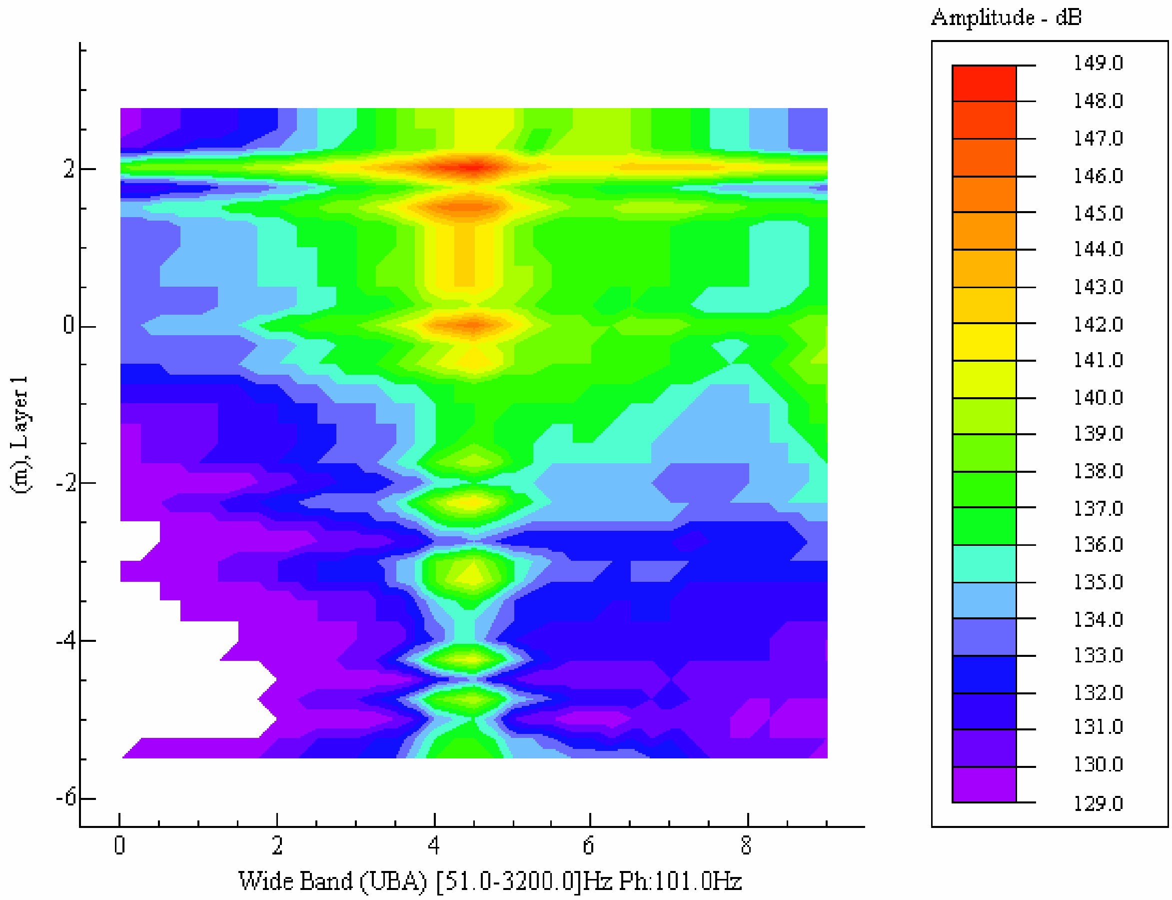
The FSRU from which the sound radiates is a distributed source and may in fact be considered the equivalent of a large number of small sources, which when added together produce the equivalent radiated noise. This means that in the near-field the sound pressures in the water are less than those implied by the equivalent source strengths quoted. However, it is not possible to predict accurately the near-field radiation pattern and hence the results are standardized by providing equivalent point source levels @ 1 m.

In the near-field close to the hull, the peak levels at any point will be less than those predicted by the simple inverse square law. It is estimated that the actual peak levels at 1 m from the hull will be more than 10 dB less than the nominal standardized source levels.

To illustrate this, the near-field radiation pattern measured at a distance of 1 m for a large machine source is presented in Figure 9-1. The standardized source level is 157 dB re 1 µPa @ 1 m, while the peak pressure measured at a distance of 1 m is 149 dB.

The more distributed the source and the larger the radiating surface then the larger the difference between the standardized level and the actual peak pressure in the near-field.

Figure 9-1: Near Field Noise Amplitudes



9.3 AIRBORNE NOISE

The equivalent airborne radiated noise for the FSRU is 127 dBA at 1 m from a theoretical point source that relates to the total sound power of the FSRU.

The airborne radiated sound power is dominated by direct radiation from the deck mounted machinery and noise radiated by the deck vibration. Both these are distributed sources. The equivalent sound pressure level at 1 m from and equivalent point source is determined by projecting the noise to a distant point (say 1 km) and then back projecting to the centerline of the ship.

The noise at the forward end of the ship is dominated by the radiated sound power from the airborne radiation from the Submerged Combustion Vaporizers and Booster Pumps on the fore deck, and the radiation from the main deck due to the vibration excited by the Booster Pumps. The high levels of radiated sound power from the main deck are partially due to the large area.

The noise at the aft end of the ship is dominated by airborne noise from the engine exhausts. The generator engine exhausts are assumed to have a basic muffler fitted and further reductions could be achieved by the inclusion of an additional muffler.

As shown in section 8.2 the total airborne noise is dominated by the noise at the forward end.

The airborne noise will decay as the square of the distance from the ship, and at 1 km the level will be 67 dB. The level will be less than 50 dBA at a distance of 5 km. When the basic noise attenuation treatments are implemented, the levels are expected to fall by 5 dB.

Because the machinery and the deck radiation are distributed, sources of the actual airborne noise level at any point on the deck will be lower than the value for the equivalent point source. The average levels on the deck are estimated to be less than 100 dBA. The exact level will depend on the proximity to the direct radiation form machinery noise sources.

During subsequent design phases the individual noise sources will be revised, and attenuated if necessary, to ensure they are within acceptable operator occupational health and safety limits.

10 REFERENCES

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Appendix A. – CJ Engineering – Background

CJ Engineering Consultants - Background

CJ Engineering Consultants have extensive experience in the following areas.

- Radiated noise prediction for naval vessels
- Analytical and numerical modelling of machinery vibration
- Modelling of vibration transmission in structures
- Vibration and acoustic measurements
- Structural vibration transmission in ships and submarines.
- Analytical and experimental modal analysis

The Principal of CJ Engineering Consultants is Dr. Christopher Norwood. His qualifications include:

- PhD (RMIT University)
- MSc (Loughborough)
- MEngSci (Melbourne University)
- BE (Hons) (Melbourne University)

Professional awards received by Dr. Norwood include;

- Australian Defence Minister's Award for Achievement in DSTO.
  Awarded for sustained and distinguished research leadership and contribution in support of noise and vibration, hydrodynamics and signature management of Australian Defence Force maritime platforms
- Maritime Platforms Division - DSTO Award for Best Advice to Defence
  Awarded for investigation into and reduction of radiated noise from machinery in the Collins class submarine fleet of the Royal Australian Navy.

In addition to his private consulting activities Dr. Norwood maintains a position as Head of the Ship Acoustics Signature Group for the Australian Defence, Science and Technology Organisation He is responsible for investigating structural vibration transmission in, and acoustics radiation from, ships and submarines

Projects undertaken by Dr. Norwood for DSTO include the investigation into the radiated noise from the ship service diesel generators on the RAN FFG-7 ships; the development of a modification package for the FFG-7's to reduce the underwater radiated noise; the analysis and estimation of the radiated noise levels from the proposed RAN air warfare destroyer; and the investigation of radiated noise sources on the Collins class submarine and the development of noise reduction procedures.

Appendix B. – Equipment List

CABRILLO PORT - TOPSIDES PROCESS EQUIPMENT LIST (TYPICAL NOISE VALUES)

Worley

CLIENT PROJECT NO.	
CLIENT DOCUMENT NO.	
WORLEY PROJECT NO.	351/05876
WORLEY DOCUMENT NO.	05876-MD-005 Rev E

REVISION	A	B	C	D	E
DATE	17/5/04	18/5/04	1/6/04	19/6/04	18/8/06
PREP. BY	PaW	PaW	PaW		JS
CHKD. BY	LF	LF	LF		
APPRV'D	LJW	LJW	LJW		

Equipment No	No. of Units Operating	No. of Units Spare	Description	Capacity per Unit	Unit Size L x W x H or T/T x ID mm	Design Code	WEIGHT Dry tonnes	WEIGHT Operating Tonnes	OCTAVE BAND FREQUENCY SOUND PRESSURE LEVEL DATA @ 1m DISTANCE 31.5 (HZ)	63 (HZ)	125 (HZ)	250 (HZ)	500 (HZ)	1000 (HZ)	2000 (HZ)	4000 (HZ)	8000 (HZ)	Linear	dB (A) Unattenuated	dB (A) Attenuated	Case 1 Base Case, 800 MMSCFD Operating yes/nc	Case 2 1.5 BSCFD Operating yes/nc	Case 3 Base case plus suppression Operating yes/nc	Case 4 Base case plus carrier along sde. No tugs Operating yes/nc	Case 5 Base case plus tugs plus carrier Operating yes/nc	Case 5 1.5 Bscfd with tugs and carrier Operating yes/nc	Case 6 1.5 Bscfd with IGG operating Operating yes/nc	Comments	REV
100			**LOADING , STORAGE AND REFGASIFICATION**																										
F101A/B/C/D/E/F/G/H	8	0	SUBMERGED COMBUSTION VAPORISER (PACKAGE)	180 tonne/hour LNG vapourisation capacity	14000*4200*3500		89.1	206.1		80	86	91	97	107	111	116	111		118.5	88	5	8	5	5	5	8	8	Lube for blower. F101G/F are future; Speed 3600 rpm Blower weight 6 tonnes	C
P100A/B/C/D/E/F	2	4	SUBMERGED LNG TRANSFER PUMP			API	4.75	4.9	80.3	89.7	83.1	77.9	74.5	71.8	79.6	75.7	70.1		83.7		1	2	1	1	1	2	2	Located in LNG Spheres; Values taken on test stand. Speed 4743 rpm	C
P101A/B/C/D/E/F	6	0	BOOSTER PUMP	Rated flow 553 m3/h Differential head 2247 m	4500*1219	API	15.05	15.4											94	88	3	6	3	3	3	6	6	P101F is future; speed 3600 rpm.	C
P102A/B/C	1	2	SUBMERGED LNG RECYCLE PUMP	120 m3/h Differential head 140 m		API													65		1	1	1	1	1	1	1		A
X100A/B/C	3		LIQUID LOADING ARM																		nil	nil	nil	3	nil	3	nil		
X101	1		VAPOUR LOADING ARM																		nil	nil	nil	1	nil	1	nil		
200			**BOIL OFF GAS HANDLING**																										
E202	1	0	HP BOIL OFF GAS COMPRESSOR INTERCOOLER -1		2440 x 1520	API			N/A	86.7	85.7	82.7	77.7	75.7	69.7	63.7	57.7		80.7		nil	nil	nil	nil	nil	1	nil	Marine grade air cooler.	A
E203	1	0	HP BOIL OFF GAS COMPRESSOR INTERCOOLER -2		2440 x 1220	API			N/A	86.7	85.7	82.7	77.7	75.7	69.7	63.7	57.7		80.7		nil	nil	nil	nil	nil	1	nil	Marine grade air cooler.	A
E204	1		HP BOIL OFF GAS COMPRESSOR AFTERCOOLER						N/A	86.7	85.7	82.7	77.7	75.7	69.7	63.7	57.7		80.7		nil	nil	nil	nil	nil	1	nil	Marine grade air cooler.	A
K201A/B/C	2	1	LP BOIL OFF GAS COMPRESSOR		8500 x 4000x 4500	API	6	6.04		48	51	54	57	62	84	78	63		90	86	2	2	2	2	2	2	2	2-Stage Centrifugal Type. Speed 3600rpm	C
K202	1	0	HP BOIL OFF GAS COMPRESSOR		12000 x 9000	API	30			81	82	82	80	80	77	69	62		84		nil	nil	nil	nil	nil	1	nil	Vertical Labyrinth Piston Type Model 4HB/3. Operates only on plant shutdown/startup. Levels are with Acoustic treatment of pulsation bottles only.	C
300			**EXPORT AND MOORING**																										
	2	0	HYDRAULIC SWIVELS																68		2	2	2	2	2	2	2	Power from Merlin Doc Ref: 2493-R010. Includes all power for control valves and power packs	A
400			**FUEL GAS, POWER GENERATION**																										
G401A/B/C/D	3	1	MAIN GAS GENERATOR DRIVERS (3 x GAS, 1 x DUAL FUEL)	8250 kW at 514 rpm / 60 Hz				137t; Genera	109	105	104	104	108	105	103	101	95	113	109		3	3	2	3	3	3	3	Gas engines type Wartsila 9L50DF. Each generator includes dedicatec cooling water system which shall include LT and HT circuits, pumps, preheater (using heat from running engine) and plate type exchanger coole with sea water.	A
G402 A	1	0	EMERGENCY GENERATOR (AFT)	1000 kW at 900 rpm / 60 Hz	6550 x 2300 x 2925				94	92	93	85	92	95	92	97	89		101.3	88	nil	nil	nil	nil	nil	nil	nil	Data based on Wartsila 9L20 diesel engine.	A
P401A/B/C/D	3	1	UREA INJECT ION PUMPS	0.4 m3/h															45		3	4	3	3	3	3	3		A
X403A/B/C/D	3	1	DENOX PACKAGES		2800 x 3000 x 5000		8			68	68	66	66	64	59	54	54		74		3	4	3	3	3	3	3	Information provided by Wartsila	C
500			**WATER**																										
P500A/B/C	2	1	SEAWATER DISTRIBUTION PUMPS	Rated flow 400 m3/h Differential head 61 m	2000 x 1500 x 1500	API	3	3.2		79	79	77	77	75	70	65	65		85		2	nil	nil	nil	nil	nil	2	Speed 3600 rpm	E
P510A/B	1	1	COOLING WATER CIRCULATION PUMPS	Rated flow 77 m3/h Differential head 71 m																		1	1	1	1	1	1		E
P520A/B	1	1	SERVICE WATER PUMP	Rated flow 50 m3/h Differential head 71 m	800 x 600x 1000	API				69	69	67	67	65	60	55	55		75		1	1	1	1	1	1	1	10 m3/h estimated by Costain too low, use 50m3/hr (one hose)	A
P521	1	0	FIREWATER JOCKEY PUMP	Rated flow 120 m3/h Differential head 70 m	800 x 600x 1000	API	1	1.1		69	73	73	71	71	71	69	64		79		1	1	1	1	1	1	1	Two hydrants in use; speed 3600 rpm	C
P530A/B	1	1	FRESH WATER PUMPS	Rated flow 25 m3/h Differential head 70 m	800 x 600x 1000	API				70	70	68	68	66	61	56	56		76		1	1	1	1	1	1	1		A
P540A/B/C/D	2	2	FIRE WATER PUMPS	Rated flow 1200 m3/h Differential head 80 m	3000 x 2000 x 2000	API	8	8.2	103	120	109	107	105	107	102	89	76		111	93	1	1	1	nil	nil	nil	nil	4 x diesel; operate intermittently 4 hours per month; speed 1800 rpm **Note 1**	D
P550A/B	1	1	BALLAST WATER PUMPS		3000 x 2000 x 2000	API	3.5	3.7		81	81	79	79	77	72	67	67		87	85	1	1	1	1	1	1	1	Power from Merlin Doc Ref: 2493-R010; Speed 3600 rpm	C
P560A/B	2	0	INERT GAS GENERATOR SEAWATER SUPPLY PUMPS	Rated flow 1000 m3/h Differential head 61 m	4000 x 2500 x 2000	API				78	78	76	76	74	69	64	64		84		nil	nil	nil	nil	nil	nil	nil		A
P570A/B	1	1	F-101A SCV / COOLING WATER LOOP PUMP																		1	1	1	1	1	1	1		E
P575A/B	1	1	F-101E SCV / COOLING WATER LOOP PUMP																		nil	1	nil	nil	nil	1	1		E
X510A/B	2	0	FRESH WATER MAKING PACKAGE (2X 50%)	0.5 m3/h	5000 x 2000 x2000					61	65	65	63	63	63	61	56		65		2	2	2	2	2	2	2		A
X520	1	0	HYPOCHLORITE UNIT	20 m3/h seawater flow to produce 0.1% solution	3000 x 3000 x 2000					70	70	68	68	66	61	56	56		76		1	1	1	1	1	1	1		A
X530	1	0	UV STERILLISATION UNIT	1 m3/h	2000 x 2000 x 2000					67	71	71	69	69	69	67	62		77		1	1	1	1	1	1	1		A
600			**UTILITIES**																										
D600A/B	2	1	INSTRUMENT AIR DRYERS							75	75	73	73	71	66	61	61		82	70	2	2	2	2	2	2	2		D
D605	1	0	INERT GAS GENERATOR DRIER																80	70	nil	nil	nil	nil	nil	nil	1	Included in X-605	A
E605	1	0	INERT GAS COOLER						N/A	86.7	85.7	82.7	77.7	75.7	69.7	63.7	57.7		80.7		nil	nil	nil	nil	nil	nil	1	Included in X-605	A
P605A/B	1	1	INERT GAS GENERATOR PACKAGE BLOWERS			API													100	85	nil	n.l	nil	nil	nil	n.l	1		A
P610A/B	1	1	DIESEL CIRCULATION PUMP							67	71	71	69	69	69	67	62		77		1	1	1	1	1	1	1	Included in X-605	A
P620A/B/C/D/E/F/G/H	7	1	CAUSTIC DOSING PUMP	Rated flow 0.03 m3/h Differential head 100 m			0.1												45		5	8	5	5	5	8	8	Vendor advised injection rate	A
P621A/B	2	0	COOLING WATER CHEMICAL DOSING PUMPS	0.5 m3/h															45		2	2	2	2	2	2	2		A
P622A/B	1	1	CAUSTIC TRANSFER PUMP	Rated flow 5 m3/h Differential head 50 m						61	65	65	63	63	63	61	56		71		1	1	1	1	1	1	1	Assume caustic is transferred over 1 hour per day **Note 1**	D
X601A/B	1	1	NITROGEN GENERATORS	120 Nm3/h			1.8	1.8		75	75	73	73	71	66	61	61		82		1	1	1	1	1	1	1	Included in X605 package; speed 3600 rpm	C
X605	1	0	INERT GAS GENERATOR	20000 Nm3/h	20000 X 10000 X 3000				127.8	128.5	125.8	118.8	110.8	107.6	98.7	89.8	86.8		90	85	nil	nil	nil	nil	nil	nil	1		E
C606A/B/C	2	1	AIR COMPRESSORS	750 Nm3/h	2100 X 1400 X 2000		5	5		117	109	111	103	96	104	104	98		110	78	2	2	2	2	2	2	2	Speed 3600 rpm	C
700			**VENTS AND DRAINS**																										
P701A/B	1	1	GREY WATER PUMP		800 x 600x 1000					67	67	65	65	63	58	53	53		73		1	1	1	1	1	1	1	Note 1	D
P702A/B	1	1	SEWAGE LOADOUT PUMP		800 x 600x 1000					67	67	65	65	63	58	53	53		73		1	1	1	1	1	1	1	Note 1	D
P703A/B/C/D	4	2	BILGE PUMPS		800 x 600x 1000					68	68	66	66	64	59	54	54		74		2	2	2	2	2	2	2	Power from Merlin Doc Ref: 2493-R010 **Note 1**	D
P704A/B	1	1	CONTAMINATED WATER TRANSFER PUMP		800 x 600x 1000					67	67	65	65	63	58	53	53		73		2	2	2	2	2	2	2	Note 1	D
P705A/B	1	1	CONTAMINATED WATER LOADOUT PUMP		800 x 600x 1000					67	67	65	65	63	58	53	53		73		1	1	1	1	1	1	1	Note 1	D
P706A/B	1	1	PRODUCED WATER PUMP							68	68	66	66	64	59	54	54		74		1	1	1	1	1	1	1	Note 1	D
P707A/B	1	1	SEWAGE TANK PUMPS FORE							68	68	66	66	64	59	54	54		74		1	1	1	1	1	1	1	Note 1	D
X701	1	0	SEWAGE TREATMENT (AFT)							67	67	65	65	63	58	53	53		73		1	1	1	1	1	1	1	Power from Merlin Doc Ref: 2493-R010 **Note 1**	D
800			**SAFETY**																										
	1	0	HVAC UNIT FOR EMERGENCY ESCAPE ROUTE PRESSURISATION							87	82	80	74	73	74	70	62		80		1	1	1	1	1	1	1		A
	1	0	HVAC UNIT FOR TR ELEMENT OF ACCOMMODATION							87	82	80	74	73	74	70	62		80		1	1	1	1	1	1	1		A
																													A
900			**MISCELLANEOUS**																										
	2	0	CRANES - AFT	40 TONNE @45M															70		1	1	1	1	1	1	1	Note 1	D
	2	0	HVAC MAIN - ACCOMMODATION (2x 50%)				2.2	2.2		96	89	86	80	80	79	78	70		86		2	2	2	2	2	2	2	Includes All HVAC power from Merlin Doc Ref 2493-R010; speed 1800 rpm	C
	2	0	HVAC - FORE (2 x 50%)				1	1		96	89	86	80	80	79	78	70		86		2	2	2	2	2	2	2	Power included in HVAC Main Accommodation; speed 1800 rpm	C
	1	0	VENTILATION FANS ACCESS WAY (1 x 100%)				0.75	0.75											90	86	1	1	1	1	1	1	1	speed 1800 rpm	C
	1	0	VENTILATION FANS AFT (1 x 100%)				0.75	0.75											90	86	1	1	1	1	1	1	1	speed 1800 rpm	C
	1	0	VENTILATION FANS FORE (1 x 100%)				0.75	0.75											90	86	1	1	1	1	1	1	1	speed 1800 rpm	C

Worley

CABRILLO PORT - TOPSIDES PROCESS EQUIPMENT LIST (TYPICAL NOISE VALUES)

CLIENT PROJECT NO.	
CLIENT DOCUMENT NO.	
WORLEY PROJECT NO.	351/05876
WORLEY DOCUMENT NO.	05876-MD-005 Rev E

REVISION	A	B	C	D	E
DATE	17/5/04	18/5/04	1/6/04	19/6/04	18/8/06
PREP. BY	PaW	PaW	PaW		JS
CHKD. BY	LF	LF	LF		
APPRV'D	LJW	LJW	LJW		

Equipment No	No. of Units Operating	Spare	Description	Capacity per Unit	Unit Size L x W x H or T/T x ID mm	Design Code	WEIGHT Dry tonnes	Operating Tonnes	OCTAVE BAND FREQUENCY SOUND PRESSURE LEVEL DATA @ 1m DISTANCE 31.5 (HZ)	63 (HZ)	125 (HZ)	250 (HZ)	500 (HZ)	1000 (HZ)	2000 (HZ)	4000 (HZ)	8000 (HZ)	Linear	dB (A) Unattenuated	dB (A) Attenuated	Case 1 Base Case, 800 MMSCFD Operating yes/nc	Case 2 1.5 BSCFD Operating yes/nc	Case 3 Base case plus suppression Operating yes/nc	Case 4 Base case plus carrier along sde. No tugs Operating yes/nc	Case 5 Base case plus tugs plus carrier Operating yes/nc	Case 5 1.5 Bscfd with tugs and carrier Operating yes/nc	Case 6 1.5 Bscfd with IGG operating Operating yes/nc	**Comments**	**REV**
	2	0	THRUSTERS A/B						90	85	85	90	80	75	60	N/A	N/A		80	75	nil	nil	nil	1 (3MW)	1 (3MW)	1 (3MW)	nil	Thrusters have 100% reduncancy	A
	2	0	WINCHES - FORE / AFT						66	70	72	78	80	74	72	68	60		83.8		nil	nil	nil	nil	nil	nil	nil	Operates Intermittently	A
X900A	1	0	CRANES - PROCESS 1	15 Tonne @45M															70		1	1	1	1	1	1	1	Note 1	D
X900B	1	0	CRANES - PROCESS 2	15 Tonne @45M															70		nil	nil	nil	nil	nil	nil	nil	Note 1	D
LNG Carrier																								note 3	note 4	note 4			
Tug 1																									YES	YES			
Tug 2																									YES	YES			

Notes
1 Assume ?MW of minor users
2 Assume ??MW of minor users
3 The carrier will have LNG transfer pumps and basic ship systems operating
4 The carrier will have basic ship systems operating

Appendix C. – Noise and Vibration Source Data

Source Vibration Levels re 10-6 cm/s - Equipment at Fore End of Vessel

				1	2	3	4	5	6	7	8	9
Equip	Description	Location	Power kW	31.5 (HZ)	63 (HZ)	125 (HZ)	250 (HZ)	500 (HZ)	1000 (HZ)	2000 (HZ)	4000 (HZ)	8000 (HZ)
F101-Star	Submerged Combustion Vaporiser	PD-Fore	328	100	108	112	101	95	94	93	87	86
F101-Port	Submerged Combustion Vaporiser	PD-Fore	328	100	108	112	101	95	94	93	87	86
P101	Booster Pump	PD-Aft	2305	109	111	118	110	108	103	93	91	84
K201	LP Boil Off Gas Compressor	PD-Aft	306	100	108	112	101	95	94	93	87	86
Hyd	Hydraulic Swivels	UD 2F	42	102	106	111	112	115	109	104	99	84
HVAC2	HVAC - FORE (2 X 50%)	UD 2F	40	112	113	110	103	95	92	83	74	71
Fans	Ventilation Fans	UD 2F	40	100	94	88	82	76	70	64	58	52
P521	Firewater Jockey Pump	UD 2F	33	100	96	99	92	89	84	75	72	65
Pumps-UD2F	Caustic Trans. + Produced Water Pump	UD 2F	29	99	95	99	91	89	84	74	72	65
P540	Fire Water Pump	UD 5F	365	103	103	110	102	100	95	85	83	76
Misc-UD5F	Bilge And Sewerage Tank Pumps	UD 5F	30	99	95	99	91	89	84	74	72	65

Source Vibration Levels re 10-6 cm/s - Equipment at Aft End of Vessel

Equip	Description	Floor	Power kW	31.5 (HZ)	63 (HZ)	125 (HZ)	250 (HZ)	500 (HZ)	1000 (HZ)	2000 (HZ)	4000 (HZ)	8000 (HZ)
Misc-UD2M	Equipment Group - UD2 Mezzanine	UD 2 Mez	42	112	113	110	103	95	92	83	74	71
HVAC1	HVAC Main- Accommodation (2x 50%)	UD 2 Mez	135	117	118	115	108	100	97	88	79	76
X403	Denox Packages	UD 2	10	99	94	95	87	85	79	70	67	61
G401Eng	(3 X GAS, 1 X DUAL FUEL)	UD 3	8500	119	107	107	106	105	105	101	93	82
G401 Gen	Main Gas Generators	UD 3	8200	114	119	116	110	106	101	96	90	84
D600	Instrument Air Dryers	UD 4	40	112	113	110	103	95	92	83	74	71
Misc-UD4	Equipment Group - UD4	UD 4	51	100	97	101	93	91	86	76	74	67
X601	Nitrogen Generators	UD 4	60	114	115	112	105	97	94	85	76	73
C606	Air Compressors	UD 4	212	102	96	90	84	78	72	66	60	54
P500	Seawater Distribution Pumps	UD 5	115	101	99	105	97	95	90	80	78	71
P510	Cooling Water Circulation Pumps	UD 5	21	99	95	98	90	87	82	73	70	63
P550	Ballast Water Pumps	UD 5	210	102	101	107	99	97	92	82	80	73
Misc-UD5A	Equipment Group - UD5A	UD 5	27	99	95	99	91	89	83	74	71	65

Sound Pressure Levels - Source Data

Equipment No	Description	Location	Deck Level	Electrical Power	OCTAVE BAND FREQUENCY SOUND PRESSURE LEVEL DATA @ 1m DISTANCE									dB (A)	dB (A)
				kW	31.5 (HZ)	63 (HZ)	125 (HZ)	250 (HZ)	500 (HZ)	1000 (HZ)	2000 (HZ)	4000 (HZ)	8000 (HZ)	Unattenuated	Attenuated
F101A/B/C/D/E/F/G/H	SUBMERGED COMBUSTION VAPORISER	Fore	Process L1	328	78	80	86	91	97	107	111	116	111	118.5	88
P101A/B/C/D/E/F	BOOSTER PUMP	Fore	Process L1	2305	Not Supplied From Manufacturer									94	88
K201A/B/C	LP BOIL OFF GAS COMPRESSOR	Fore	Process L2	306	76	77	80	82	85	85	84	79	73	90	86
	HYDRAULIC SWIVELS	Fore	UD 2	42	Not Supplied From Manufacturer									68	
G401A/B/C/D	MAIN GAS GENERATOR DRIVERS (3 x GAS, 1 x DUAL FUEL)	Aft	UD 3	8550	109	105	104	104	108	105	103	101	95	109	
G401	Generator PWL	Aft	UD 3	8250	Not Supplied From Manufacturer										
F401	Diesel Engine - Exhaust	Aft	Above Deck		Not Supplied From Manufacturer										
X403A/B/C/D	DENOX PACKAGES	Aft	UD 2	10	68	68	68	66	66	64	59	54	54	74	
P500A/B/C	SEAWATER DISTRIBUTION PUMPS	Aft	UD 5	115	79	79	79	77	77	75	70	65	65	85	
P510A/B	COOLING WATER CIRCULATION PUMPS	Aft	UD 5	21	68	68	72	72	70	70	70	68	63	78	
P520A/B	SERVICE WATER PUMP	Fore	UD 2	14	69	69	69	67	67	65	60	55	55	75	
P521	FIREWATER JOCKEY PUMP	Fore	UD 2	33	69	69	73	73	71	71	71	69	64	79	
P530A/B	FRESH WATER PUMPS	Aft	UD 4	15	70	70	70	68	68	66	61	56	56	76	
P540A/B	FIRE WATER PUMPS	Aft	UD 5	365	103	120	109	107	105	107	102	89	76	111	93
P540C/D	FIRE WATER PUMPS	Fore	UD 5	365	103	120	109	107	105	107	102	89	76	111	93
P550A/B	BALLAST WATER PUMPS	Aft	UD 5	210	81	81	81	79	79	77	72	67	67	87	85
X510A/B	FRESH WATER MAKING PACKAGE (2X 50%)	Aft	UD 5	5	61	61	65	65	63	63	63	61	56	65	
X520	HYPOCHLORITE UNIT	Aft	UD 5	15	70	70	70	68	68	66	61	56	56	76	
X530	UV STERILLISATION UNIT	Aft	UD 4	20	67	67	71	71	69	69	69	67	62	77	
D600A/B	INSTRUMENT AIR DRYERS	Aft	UD 4	40	75	75	75	73	73	71	66	61	61	80	70
P610A/B	DIESEL CIRCULATION PUMP	Aft	UD 4	20	67	67	71	71	69	69	69	67	62	77	
P622A/B	CAUSTIC TRANSFER PUMP	Fore	UD 2	5	61	61	65	65	63	63	63	61	56	71	
X601A/B	NITROGEN GENERATORS	Aft	UD 4	60	75	75	75	73	73	71	66	61	61	85	
C606A/B/C	AIR COMPRESSORS	Aft	UD 4	212	112	117	109	111	103	96	104	104	98	110	78
P701A/B	GREY WATER PUMP	Aft	UD 4	7	67	67	67	65	65	63	58	53	53	73	
P702A/B	SEWAGE LOADOUT PUMP	Aft	UD 5	7	67	67	67	65	65	63	58	53	53	73	
P703A/B	BILGE PUMPS	Aft	UD 5	10	68	68	68	66	66	64	59	54	54	74	
P703C/D	BILGE PUMPS	Fore	UD 5	10	68	68	68	66	66	64	59	54	54	74	
P704A/B	CONTAMINATED WATER TRANSFER PUMP	Aft	UD 4	7	67	67	67	65	65	63	58	53	53	73	

Sound Pressure Levels - Source Data

Equipment No	Description	Location	Deck Level	Electrical Power	OCTAVE BAND FREQUENCY SOUND PRESSURE LEVEL DATA @ 1m DISTANCE									dB (A)	dB (A)
				kW	31.5 (HZ)	63 (HZ)	125 (HZ)	250 (HZ)	500 (HZ)	1000 (HZ)	2000 (HZ)	4000 (HZ)	8000 (HZ)	Unattenuated	Attenuated
P705A/B	CONTAMINATED WATER LOADOUT PUMP	Aft	UD 4	7	67	67	67	65	65	63	58	53	53	73	
P706A/B	PRODUCED WATER PUMP	Fore	UD 2	10	68	68	68	66	66	64	59	54	54	74	
P707A/B	SEWAGE TANK PUMPS FORE	Fore	UD 5	10	68	68	68	66	66	64	59	54	54	74	
X701	SEWAGE TREATMENT (AFT)			8	67	67	67	65	65	63	58	53	53	73	
HVAC3	HVAC UNIT FOR EMERGENCY ESCAPE ROUTE PRESSURISATION	Aft	UD 2	20	86	87	82	80	74	73	74	70	62	80	
HVAC4	HVAC UNIT FOR TR ELEMENT OF ACCOMMODATION	Aft	UD 2	20	86	87	82	80	74	73	74	70	62	80	
Crane_aft	CRANES - AFT	Aft	Above Deck	20	Not Supplied From Manufacturer									70	
HVAC1	HVAC MAIN - ACCOMMODATION (2x 50%)	Aft	UD 2	135	95	96	89	86	80	80	79	78	70	86	
HVAC2	HVAC - FORE (2 x 50%)	Fore	UD 2	40	95	96	89	86	80	80	79	78	70	86	
Fan1	VENTILATION FANS ACCESS WAY (1 x 100%)	Fore	UD 2	40			Not Supplied From Manufacturer							90	86
Fan2	VENTILATION FANS AFT (1 x 100%)	Aft	UD 2	40	Not Supplied From Manufacturer									90	86
Fan3	VENTILATION FANS FORE (1 x 100%)	Fore	UD 2	40	Not Supplied From Manufacturer									90	86
thrusters	THRUSTERS A/B	Aft	Under Hull	3000	Not Supplied From Manufacturer										
X900A	CRANES - PROCESS 1	Fore	Above Deck	20	Not Supplied From Manufacturer									70	

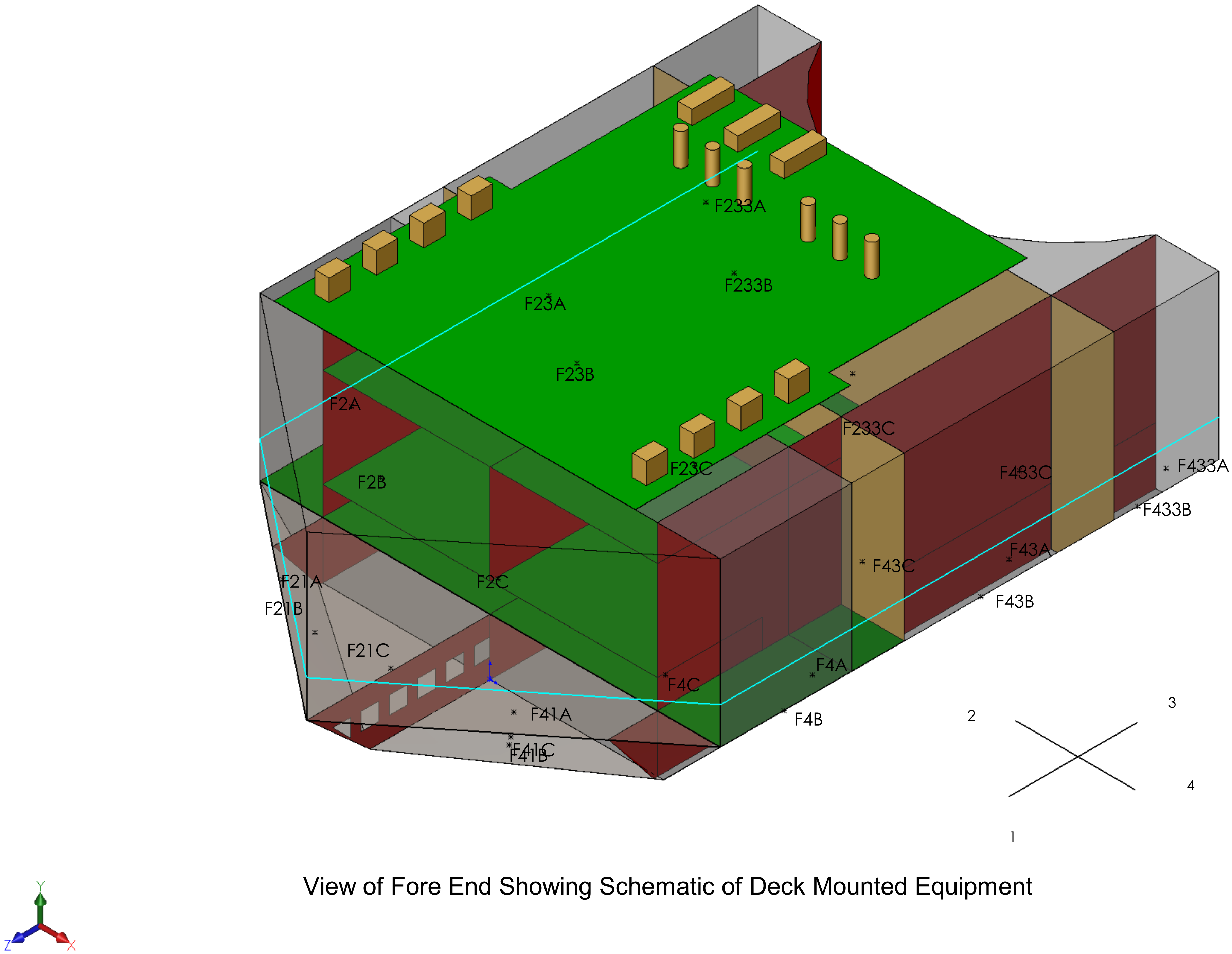
Calculated Sound power Levels

Equipment No	Description	Location	Deck Level	Electrical Power kW	OCTAVE BAND FREQUENCY SOUND POWER LEVEL DATA 31.5 (HZ)	63 (HZ)	125 (HZ)	250 (HZ)	500 (HZ)	1000 (HZ)	2000 (HZ)	4000 (HZ)	8000 (HZ)	Calculated from SPL Data ?
F101A/B/C/D/E/F/G/H	SUBMERGED COMBUSTION VAPORISER	Fore	Process L1	328	94.81	96.81	102.81	107.81	113.81	123.81	127.81	132.81	127.81	Yes
P101A/B/C/D/E/F	BOOSTER PUMP	Fore	Process L1	2305	109	110	114	118	119	119	118	112	105	Empirical
K201A/B/C	LP BOIL OFF GAS COMPRESSOR	Fore	Process L2	306	92.81	93.81	96.81	98.81	101.81	101.81	100.81	95.81	89.81	Yes
	HYDRAULIC SWIVELS	Fore	UD 2	42	80	86	90	96	104	100	97	90	84	Empirical
G401A/B/C/D	MAIN GAS GENERATOR DRIVERS (3 x GAS, 1 x DUAL FUEL)	Aft	UD 3	8550	119.99	115.99	114.99	114.99	118.99	115.99	113.99	111.99	105.99	Yes
G401	Generator PWL	Aft	UD 3	8250	100	103	103	105	105	104	102	100	97	Empirical
F401	Diesel Engine - Exhaust	Aft	Above Deck		138	132	137	131	123	119	113	103	95	Empirical
X403A/B/C/D	DENOX PACKAGES	Aft	UD 2	10	83.38	83.38	83.38	81.38	81.38	79.38	74.38	69.38	69.38	Yes
P500A/B/C	SEAWATER DISTRIBUTION PUMPS	Aft	UD 5	115	96.75	96.75	96.75	94.75	94.75	92.75	87.75	82.75	82.75	Yes
P510A/B	COOLING WATER CIRCULATION PUMPS	Aft	UD 5	21	83.38	83.38	87.38	87.38	85.38	85.38	85.38	83.38	78.38	Yes
P520A/B	SERVICE WATER PUMP	Fore	UD 2	14	84.38	84.38	84.38	82.38	82.38	80.38	75.38	70.38	70.38	Yes
P521	FIREWATER JOCKEY PUMP	Fore	UD 2	33	84.38	84.38	88.38	88.38	86.38	86.38	86.38	84.38	79.38	Yes
P530A/B	FRESH WATER PUMPS	Aft	UD 4	15	85.38	85.38	85.38	83.38	83.38	81.38	76.38	71.38	71.38	Yes
P540A/B	FIRE WATER PUMPS	Aft	UD 5	365	122.24	139.24	128.24	126.24	124.24	126.24	121.24	108.24	95.24	Yes
P540C/D	FIRE WATER PUMPS	Fore	UD 5	365	122.24	139.24	128.24	126.24	124.24	126.24	121.24	108.24	95.24	Yes
P550A/B	BALLAST WATER PUMPS	Aft	UD 5	210	100.24	100.24	100.24	98.24	98.24	96.24	91.24	86.24	86.24	Yes
X510A/B	FRESH WATER MAKING PACKAGE (2X 50%)	Aft	UD 5	5	81.33	81.33	85.33	85.33	83.33	83.33	83.33	81.33	76.33	Yes
X520	HYPOCHLORITE UNIT	Aft	UD 5	15	89.78	89.78	89.78	87.78	87.78	85.78	80.78	75.78	75.78	Yes
X530	UV STERILLISATION UNIT	Aft	UD 4	20	85.57	85.57	89.57	89.57	87.57	87.57	87.57	85.57	80.57	Yes
D600A/B	INSTRUMENT AIR DRYERS	Aft	UD 4	40	94.83	94.83	94.83	92.83	92.83	90.83	85.83	80.83	80.83	Yes
P610A/B	DIESEL CIRCULATION PUMP	Aft	UD 4	20	84.03	84.03	88.03	88.03	86.03	86.03	86.03	84.03	79.03	Yes
P622A/B	CAUSTIC TRANSFER PUMP	Fore	UD 2	5	76.38	76.38	80.38	80.38	78.38	78.38	78.38	76.38	71.38	Yes
X601A/B	NITROGEN GENERATORS	Aft	UD 4	60	93.13	93.13	93.13	91.13	91.13	89.13	84.13	79.13	79.13	Yes
C606A/B/C	AIR COMPRESSORS	Aft	UD 4	212	130.27	135.27	127.27	129.27	121.27	114.27	122.27	122.27	116.27	Yes
P701A/B	GREY WATER PUMP	Aft	UD 4	7	82.38	82.38	82.38	80.38	80.38	78.38	73.38	68.38	68.38	Yes
P702A/B	SEWAGE LOADOUT PUMP	Aft	UD 5	7	82.38	82.38	82.38	80.38	80.38	78.38	73.38	68.38	68.38	Yes
P703A/B	BILGE PUMPS	Aft	UD 5	10	83.38	83.38	83.38	81.38	81.38	79.38	74.38	69.38	69.38	Yes
P703C/D	BILGE PUMPS	Fore	UD 5	10	83.38	83.38	83.38	81.38	81.38	79.38	74.38	69.38	69.38	Yes

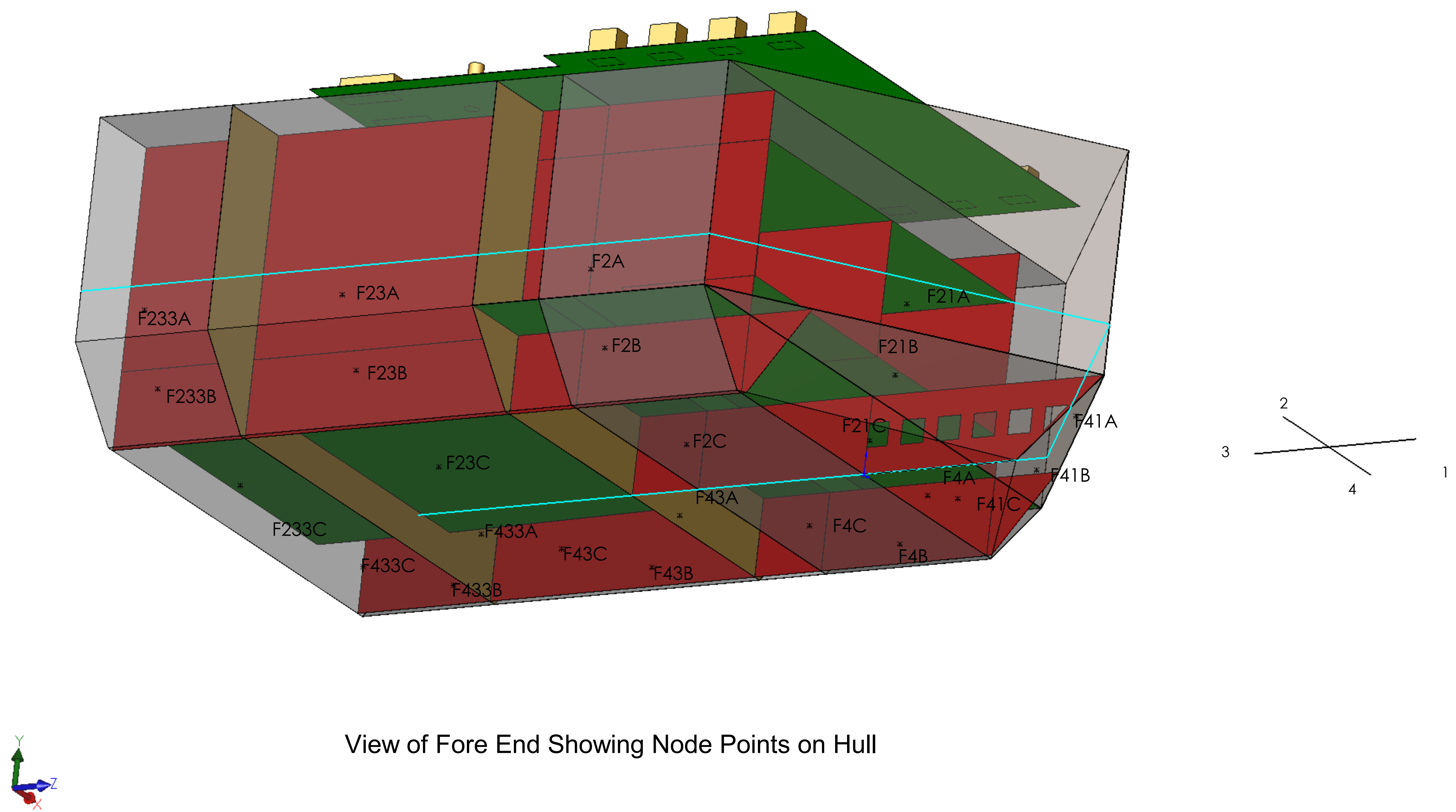
Calculated Sound power Levels

Equipment No	Description	Location	Deck Level	Electrical Power	OCTAVE BAND FREQUENCY SOUND POWER LEVEL DATA									Calculated from SPL Data ?
				kW	31.5 (HZ)	63 (HZ)	125 (HZ)	250 (HZ)	500 (HZ)	1000 (HZ)	2000 (HZ)	4000 (HZ)	8000 (HZ)	
P704A/B	CONTAMINATED WATER TRANSFER PUMP	Aft	UD 4	7	82.38	82.38	82.38	80.38	80.38	78.38	73.38	68.38	68.38	Yes
P705A/B	CONTAMINATED WATER LOADOUT PUMP	Aft	UD 4	7	82.38	82.38	82.38	80.38	80.38	78.38	73.38	68.38	68.38	Yes
P706A/B	PRODUCED WATER PUMP	Fore	UD 2	10	83.38	83.38	83.38	81.38	81.38	79.38	74.38	69.38	69.38	Yes
P707A/B	SEWAGE TANK PUMPS FORE	Fore	UD 5	10	83.17	83.17	83.17	81.17	81.17	79.17	74.17	69.17	69.17	Yes
X701	SEWAGE TREATMENT (AFT)			8	85.57	85.57	85.57	83.57	83.57	81.57	76.57	71.57	71.57	Yes
HVAC3	HVAC UNIT FOR EMERGENCY ESCAPE ROUTE PRESSURISATION	Aft	UD 2	20	101.91	102.91	97.91	95.91	89.91	88.91	89.91	85.91	77.91	Yes
HVAC4	HVAC UNIT FOR TR ELEMENT OF ACCOMMODATION	Aft	UD 2	20	101.91	102.91	97.91	95.91	89.91	88.91	89.91	85.91	77.91	Yes
Crane_aft	CRANES - AFT	Aft	Above Deck	20	80	81	85	89	90	90	89	83	76	Empirical
HVAC1	HVAC MAIN - ACCOMMODATION (2x 50%)	Aft	UD 2	135	113.57	114.57	107.57	104.57	98.57	98.57	97.57	96.57	88.57	Yes
HVAC2	HVAC - FORE (2 x 50%)	Fore	UD 2	40	113.57	114.57	107.57	104.57	98.57	98.57	97.57	96.57	88.57	Yes
Fan1	VENTILATION FANS ACCESS WAY (1 x 100%)	Fore	UD 2	40	93.21	98.21	94.21	94.21	93.21	92.21	87.21	83.21	78.21	Empirical
Fan2	VENTILATION FANS AFT (1 x 100%)	Aft	UD 2	40	93.21	98.21	94.21	94.21	93.21	92.21	87.21	83.21	78.21	Empirical
Fan3	VENTILATION FANS FORE (1 x 100%)	Fore	UD 2	40	93.21	98.21	94.21	94.21	93.21	92.21	87.21	83.21	78.21	Empirical
thrusters	THRUSTERS A/B	Aft	Under Hull	3000										Empirical
X900A	CRANES - PROCESS 1	Fore	Above Deck	20	80	81	85	89	90	90	89	83	76	Empirical

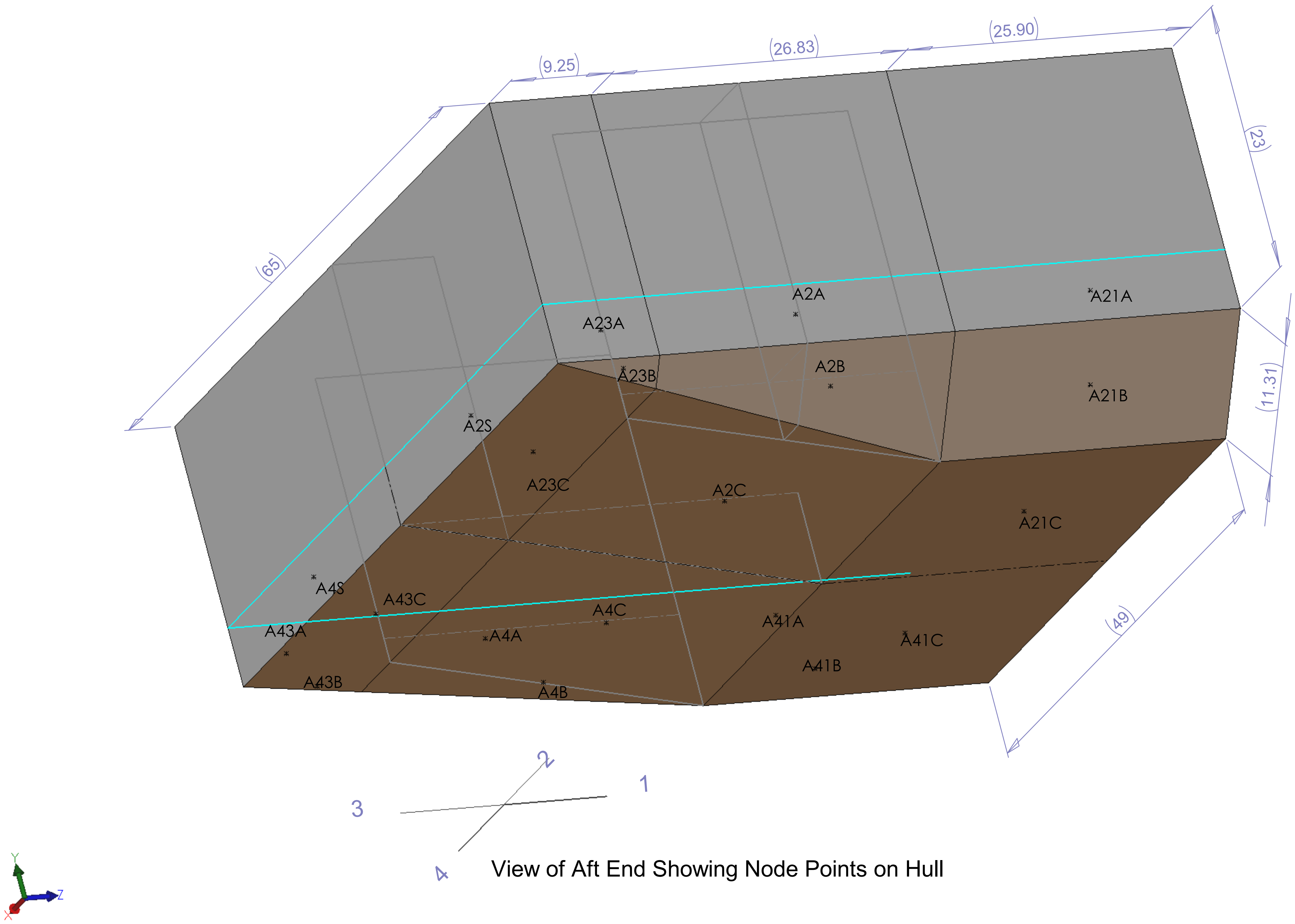
Appendix D. – Transmission Paths



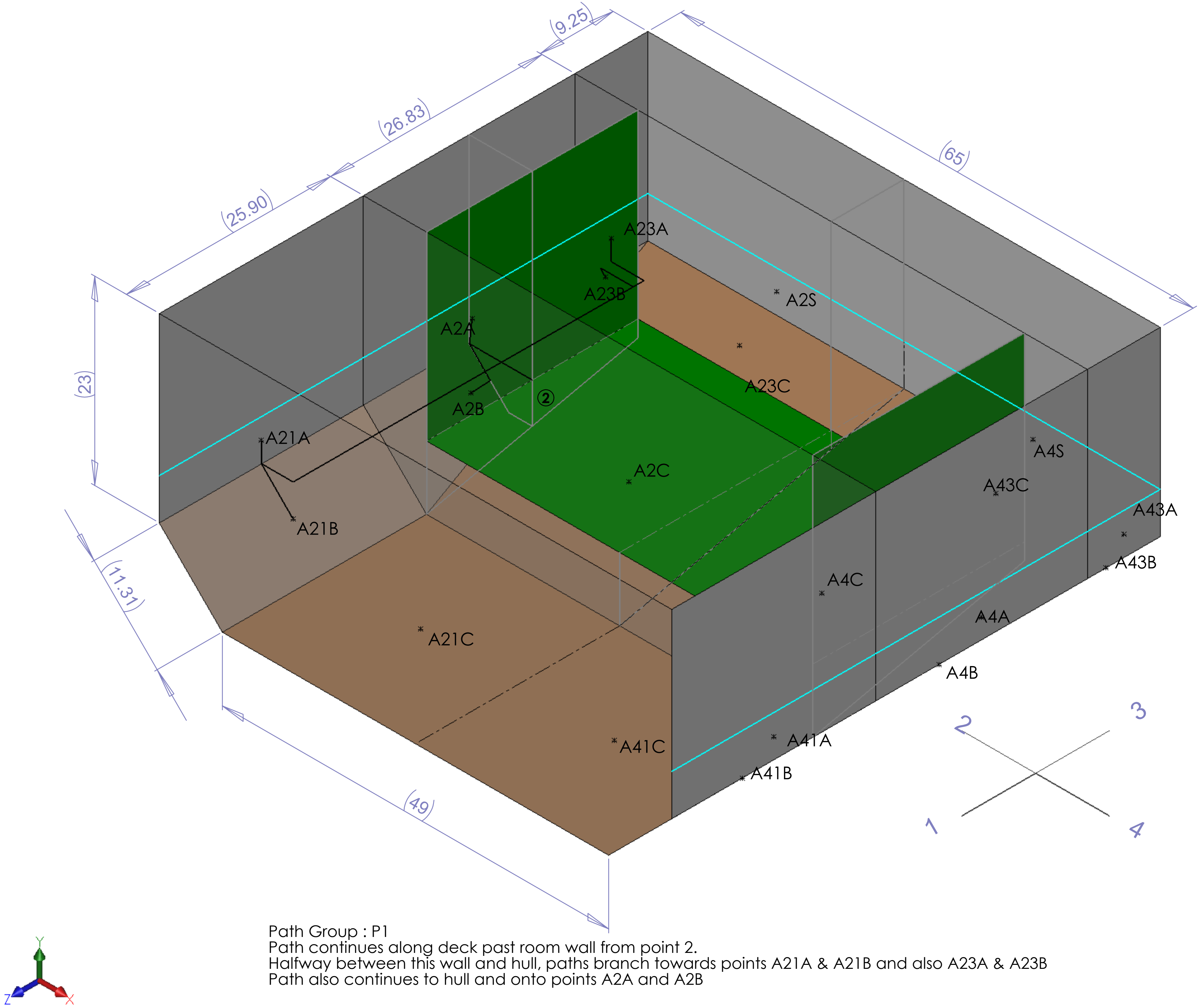
View of Fore End Showing Schematic of Deck Mounted Equipment



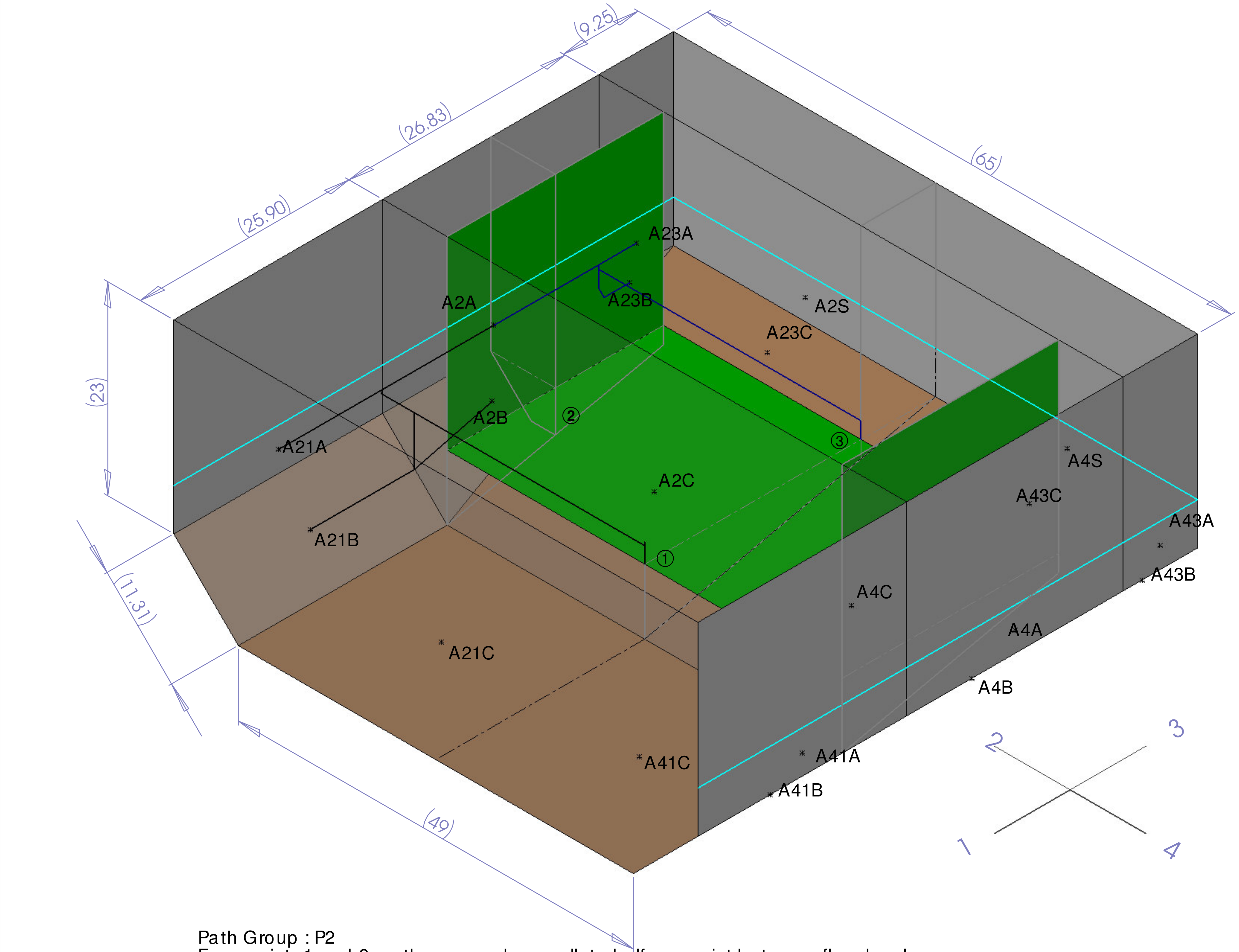
View of Fore End Showing Node Points on Hull



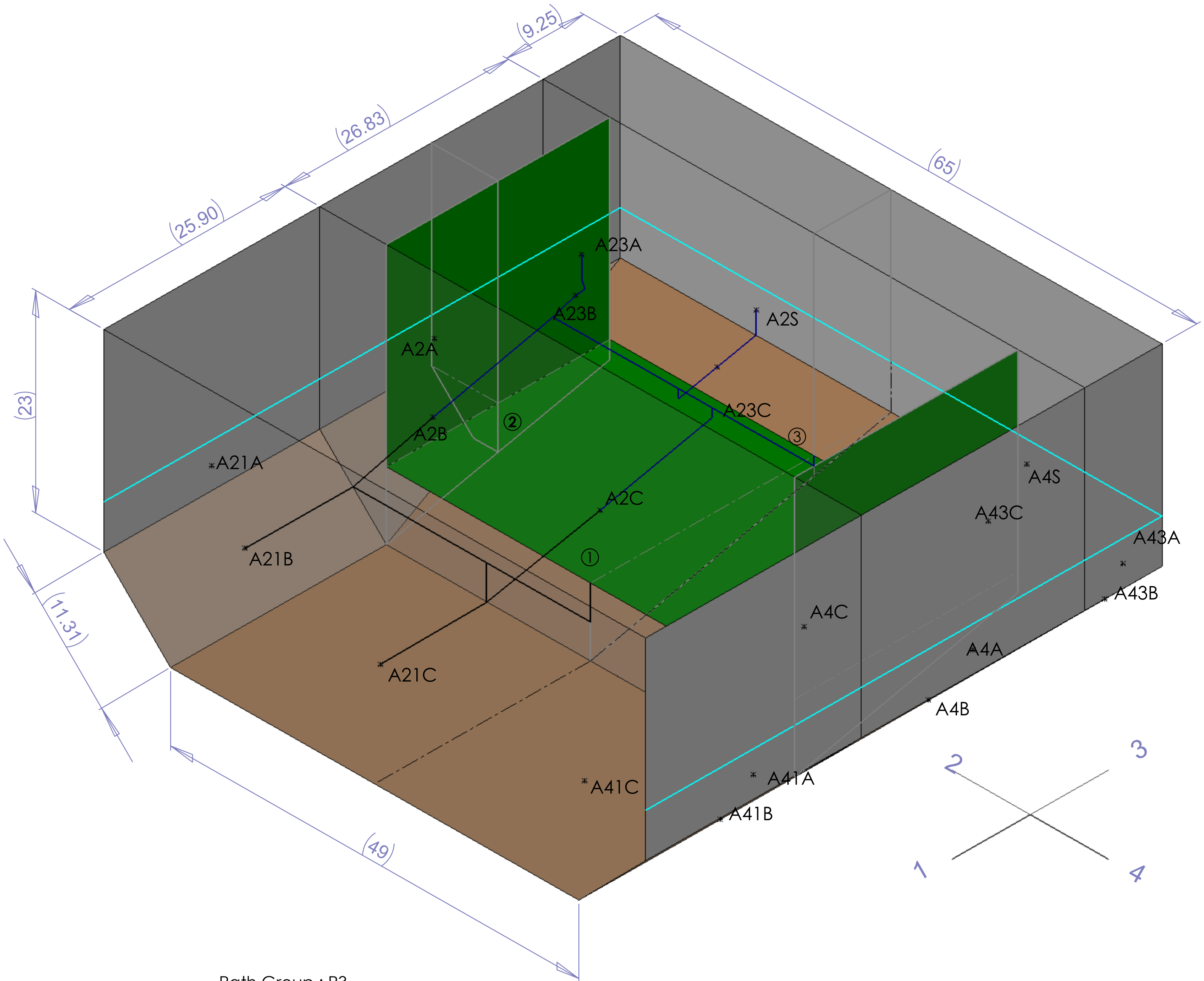
View of Aft End Showing Node Points on Hull



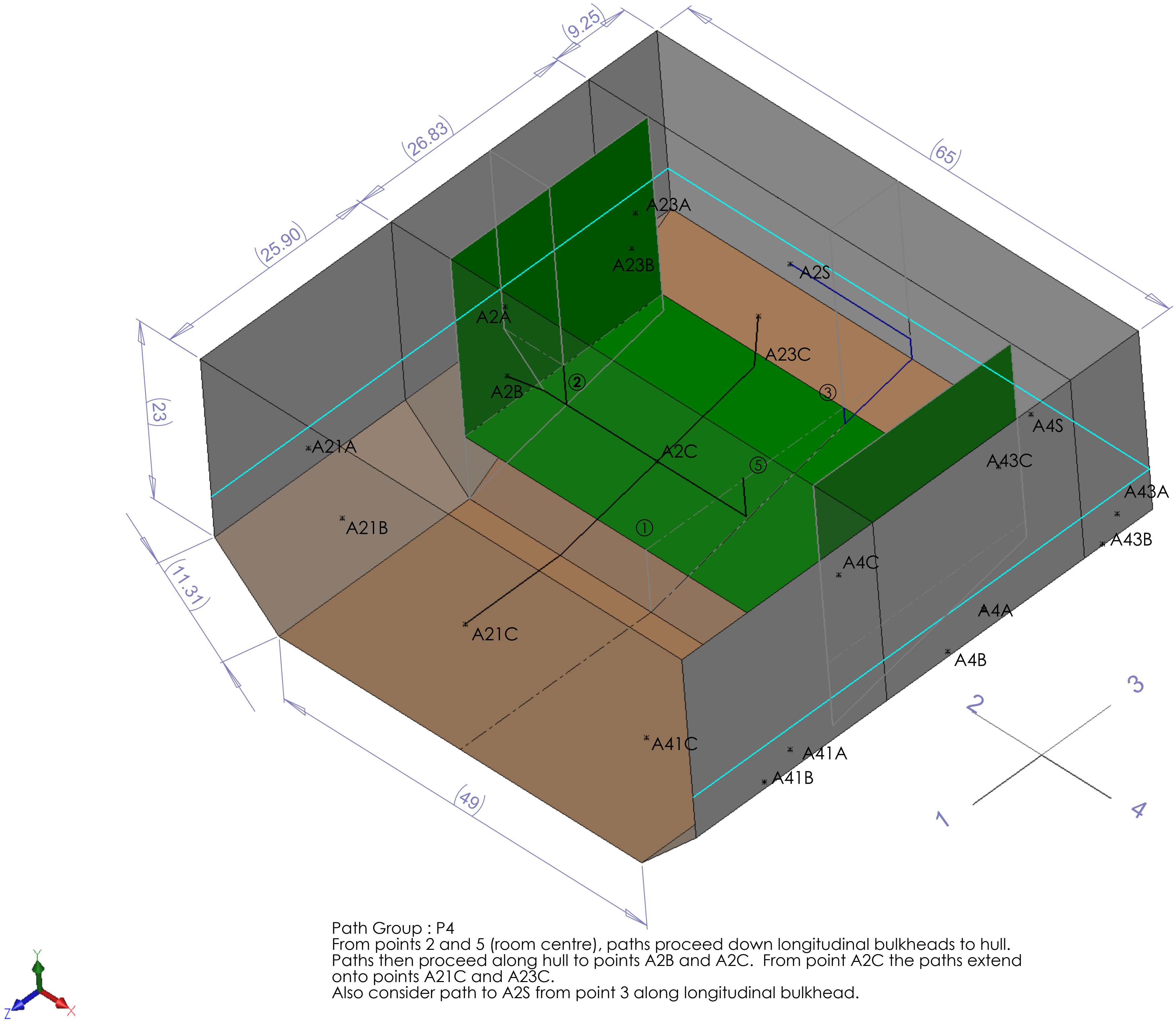
Path Group : P1
Path continues along deck past room wall from point 2.
Halfway between this wall and hull, paths branch towards points A21A & A21B and also A23A & A23B
Path also continues to hull and onto points A2A and A2B



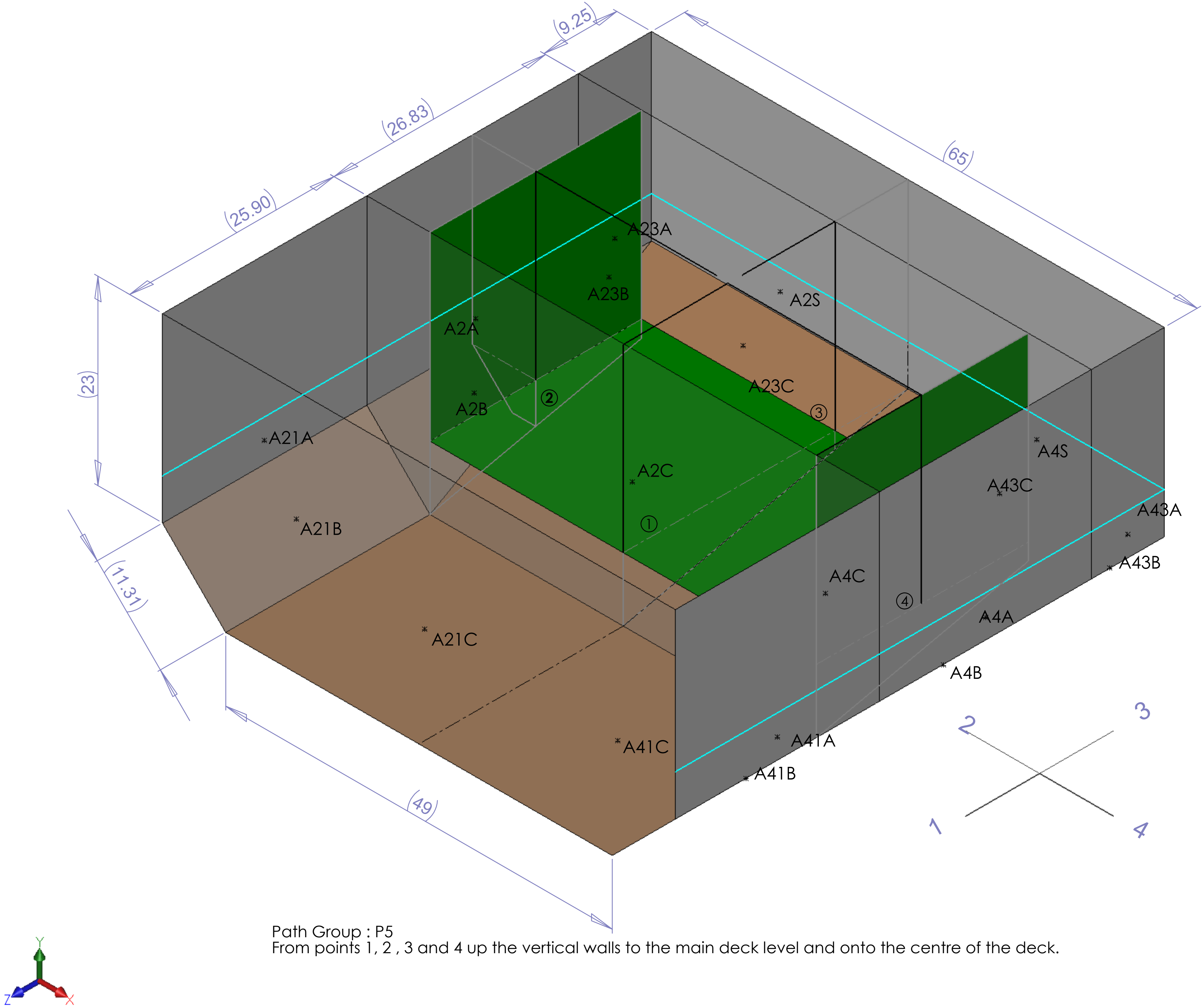
Path Group : P2
From points 1 and 3, paths proceed up walls to halfway point between floor levels.
Paths then proceed along transverse bulkhead to hull and onto points A21A, A2A and A23A.
From points A21A and A23A the paths continue onto A21B and A23B respectively.
A path also exists to A2B but not via A2A since a shorter path exists via the transverse bulkhead as shown.



Path Group : P3
From points 1 and 3, paths proceed down bulkheads to halfway point between floor and bottom hull.
Paths then proceed along transverse bulkhead to hull and onto points A21B & A21A, A2B and A23B &A23A



Path Group : P4
From points 2 and 5 (room centre), paths proceed down longitudinal bulkheads to hull.
Paths then proceed along hull to points A2B and A2C. From point A2C the paths extend onto points A21C and A23C.
Also consider path to A2S from point 3 along longitudinal bulkhead.



Path Group : P5
From points 1, 2 , 3 and 4 up the vertical walls to the main deck level and onto the centre of the deck.

Generic Tranmission Paths for Room UD5-Aft

These distances are based on the equipment being in the centre of the room.

					Direction Multiplier				Assumed Transmission Losses for various Joints (dB)											
					0.5	1	0.5	1	7	5	7	6	9	10	15	6	13	9	4	3
No. of Paths	Path	Node Point	Source Position		Length of Unwetted Steel - Parallel	Length of Unwetted Steel - Perpen	Length of Wetted Hull - Parallel	Length of Wetted Hull - Perpen												
					Code--->				T1	T2	T3	T4	T5	X1	X2	X3	X4	X5	C1	B1
4	P5	AMD	1	Main Deck	23	13.4				3		1					1			
	P5	AMD	2		47.5					3		1					1			
	P5	AMD	3		23	13.4				3		1					1			
	P5	AMD	4		47.5					3		1					1			
3	P1	A2A	2	Starboard	8.9		2.5						1		1					
	P2	A2A	1		34.5			13.4			1			1			1			
	P2	A2A	3		34.5			13.4			1			1			1			
5	P1	A2B	2		8.9		4	2.5					1		1					
	P2	A2B	1		36.5			9.4			1					1	1	1		
	P3	A2B	1		32.5			9.4			1						1	1		
	P3	A2B	3		30			17.4	1		2		1							
	P4	A2B	2		5		7				1						1		1	
4	P3	A2C	1		20.5			13.7			1						1			
	P3	A2C	3		14.5			13.7			1		1							
	P4	A2C	2		5		12.5				1						1			
	P4	A2C	5		5		12.5				1		1					1		
3	P1	A21A	2		8.9	26.4	2.6				1				2					
	P2	A21A	1		34.5			13			1						1	1		
	P3	A21A	1		29		8.6	13			2						1		1	
3	P1	A21B	2		8.9	26.4	6				1				2					
	P2	A21B	1		36.5			13			1					1	1	1	1	
	P3	A21B	1		29			13			1						1	1		
3	P3	A21C	1		20.2			13			1						1			
	P4	A21C	2		5		12.5	26.4			1						1			
	P4	A21C	5		5		12.5	26.4			1		1							
3	P1	A23A	2		9	17.4	2.6	4.1			1		1		1					
	P2	A23A	3		32.5			4.1			1		1							
	P3	A23A	3		33		3.6	4.1			2		1							
3	P1	A23B	2		9	17.4		3			1		1		1					
	P2	A23B	3		34.5		4	3			1		1						1	
	P3	A23B	3		33			3			2		1							
3	P3	A23C	3		14.2			4			1		1							
	P4	A23C	2		5		12.5	17.4			1						1			
	P4	A23C	5		5		12.5	17.4			1		1							
2	P3	A2S	3		14.2			11			1		1						1	
	P4	A2S	3			9.2	12.2	2.6			1				1					
3	P1	A4A	4		8.9		2.5						1		1					

Generic Tranmission Paths for Room UD5-Aft

These distances are based on the equipment being in the centre of the room.

					Direction Multiplier				Assumed Transmission Losses for various Joints (dB)											
					0.5	1	0.5	1	7	5	7	6	9	10	15	6	13	9	4	3
No. of Paths	Path	Node Point	Source Position		Length of Unwetted Steel - Parallel	Length of Unwetted Steel - Perpen	Length of Wetted Hull - Parallel	Length of Wetted Hull - Perpen												
	P2	A4A	1		34.5			13.4			1			1			1			
	P2	A4A	3		34.5			13.4			1			1			1			
5	P1	A4B	4		8.9		4	2.5					1		1					
	P2	A4B	1		36.5			9.4			1					1	1	1		
	P3	A4B	1		32.5			9.4			1						1	1		
	P3	A4B	3		30			17.4	1		2		1							
	P4	A4B	4		5		7				1						1		1	
4	P3	A4C	1		20.5			13.7			1						1			
	P3	A4C	3		14.5			13.7			1		1							
	P4	A4C	4		5		12.5				1						1			
	P4	A4C	5		5		12.5				1		1					1		
3	P1	A41A	4		8.9	26.4	2.6				1				2					
	P2	A41A	1		34.5			13			1						1	1		
	P3	A41A	1		29		8.6	13			2						1		1	
3	P1	A41B	4	Port	8.9	26.4	6				1				2					
	P2	A41B	1		32.5			13			1					1	1	1	1	
	P3	A41B	1		29			13			1						1	1		
3	P3	A41C	1		20.2			13			1						1			
	P4	A41C	4		5		12.5	26.4			1						1			
	P4	A41C	5		5		12.5	26.4			1		1							
3	P1	A43A	4		9	17.4	2.6	4.1			1		1		1					
	P2	A43A	3		32.5			4.1			1		1							
	P3	A43A	3		33		3.6	4.1			2		1							
3	P1	A43B	4		9	17.4		3			1		1		1					
	P2	A43B	3		40			3			1		1						1	
	P3	A43B	3		33			3			2		1							
3	P3	A43C	3		14.2			4			1		1							
	P4	A43C	4		5		12.5	17.4			1						1			
	P4	A43C	5		5		12.5	17.4			1		1							
2	P3	A4S	3		14.2			11			1		1						1	
	P4	A4S	3			9.2	12.2	2.6			1				1					

Appendix E. – Reference Drawings

The following documents were the key inputs to the study.

Worley Document Number	**BHPB Document Number**	**Description**	**Doc included in appendix**
Worley Drawings			
05876-PA-LI-001	WCLNG-BHP-PRO-RS-00-003	Equipment List	
05876-MA-001	WCLNG-BHP-PRO-RD-00-050	Overall Layout	
05876-MA-002	WCLNG-BHP-PRO-RD-00-051	Main Deck and Process Deck Level 1	
05876-MA-003	WCLNG-BHP-PRO-RD-00-052	Process Deck Level 2	
05876-MA-004	WCLNG-BHP-PRO-RD-00-059	Control Point Location	
05876-MA-005	WCLNG-BHP-PRO-RD-00-061	Instrument Room and Workshop	
05876-MA-006	WCLNG-BHP-PRO-RD-00-062	Navigation Bridge	
05876-MA-007	WCLNG-BHP-PRO-RD-00-075	Aft Area – Under Decks 04&05 Equipment Layout	
05876-MA-008	WCLNG-BHP-PRO-RD-00-053	Starboard Elevation	Yes
05876-MA-009	WCLNG-BHP-PRO-RD-00-054	Accommodation General Arrangement	
05876-MA-010	WCLNG-BHP-PRO-RD-00-076	Stern Elevation	Yes
05876-CC-001	WCLNG-BHP-PRO-RD-00-071	Process Deck Framing Plan & Sections	
Merlin Drawings			
0501-003-02		Typical Tank Plan	
0501-027-01		Typical LNG Tank Area Longitudinal Section	
Other			
Sketches	Sketches 1-4	Framing sketches	Yes

Appendix F. – Machinery Radiated Noise Levels

Radiated noise levels for individual machinery groups are presented in the table below. The radiated sound pressure levels in the tables below refer to the sound pressure levels at 1 meter from a point source with the equivalent total sound power.

Octave band centre frequency (Hz)										
	31.5	63	125	250	500	1000	2000	4000	8000	BB
HVAC1	133.2	156.1	152.4	141.4	137.2	133.3	125.5	117.3	117.4	157.8
X403	137.2	159.0	154.3	142.3	136.1	131.3	123.4	115.6	112.4	160.4
G401	124.1	138.6	137.4	124.8	123.9	116.6	109.1	109.3	139.3	141.3
D600	147.7	176.5	172.8	163.0	163.3	158.3	153.9	147.3	122.4	178.4
X601	146.4	167.9	163.1	150.1	143.8	138.8	130.9	122.6	128	169.2
C606	149.3	171.8	167.3	154.3	148.1	143.4	135.8	127.9	110.9	173.2
Misc-UD4	135.7	154.1	157.4	144.5	144.0	137.3	128.8	128.0	124.6	159.4
P500	131.6	151.3	156.3	144.3	145.9	139.8	130.8	129.2	124.8	158.1
P510	135.2	151.9	153.1	139.3	138.7	131.8	123.3	122.0	118.3	155.8
P550	130.6	151.5	157.0	145.0	146.7	140.6	131.5	130.0	125.6	158.7
Misc-UD5	137.5	155.4	157.5	144.7	144.1	137.5	129.2	128.5	125.3	159.9
F101-Star	130.1	159.8	160.7	144.7	141.6	138.3	137.2	131.9	132.8	163.4
F101-Port	121.3	147.8	148.7	132.5	128.9	126.1	124.5	125.2	124	151.4
P101	127.0	150.2	156.2	143.1	143.5	137.0	126.9	126.9	121.4	157.6
K201	117.5	149.1	151.3	135.2	131.7	129.3	127.9	124.5	123.2	153.5
Hydraulic packages	136.1	160.7	163.0	157.7	162.3	154.1	150.1	144.8	132.6	167.7
HVAC2	144.9	165.7	160.7	147.2	140.8	135.6	127.5	123.7	122.5	167.0
Fans	134.7	148.6	140.7	128.2	123.9	117.9	117.8	122.7	121.6	149.5
P521	132.3	148.4	150.1	136.2	135.8	128.7	120.7	121.7	119.5	152.6
Pumps – UD2F	129.8	145.6	147.1	134.1	133.7	126.6	119.0	120.9	119.4	149.7
P540	148.2	170.6	174.0	161.0	161.9	154.9	147.0	144.8	140.9	176.0
Misc-	145.6	162.7	163.3	150.4	150.2	143.1	135.3	133.1	129.3	166.3

Octave band centre frequency (Hz)										
	31.5	63	125	250	500	1000	2000	4000	8000	BB
UD5F										

Variation of Noise Levels (dB) with distance				
	1m	10m	100m	1000m
HVAC1	157.8	137.8	117.8	97.8
X403	160.4	140.4	120.4	100.4
G401	141.3	121.3	101.3	81.3
D600	178.4	158.4	138.4	118.4
X601	169.2	149.2	129.2	109.2
C606	173.2	153.2	133.2	113.2
Misc-UD4	159.4	139.4	119.4	99.4
P500	158.1	138.1	118.1	98.1
P510	155.8	135.8	115.8	95.8
P550	158.7	138.7	118.7	98.7
Misc-UD5	159.9	139.9	119.9	99.9
F101-Star	163.4	143.4	123.4	103.4
F101-Port	151.4	131.4	111.4	91.4
P101	157.6	137.6	117.6	97.6
K201	153.5	133.5	113.5	93.5
Hydraulic packages	167.7	147.7	127.7	107.7
HVAC2	167.0	147.0	127.0	107.0
Fans	149.5	129.5	109.5	89.5
P521	152.6	132.6	112.6	92.6

Variation of Noise Levels (dB) with distance				
	1m	10m	100m	1000m
Pumps – UD2F	149.7	129.7	109.7	89.7
P540	176.0	156.0	136.0	116.0
Misc-UD5F	166.3	146.3	126.3	106.3

All levels are referenced to 1 µPa at 1 m